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Creating a framework for systems-based graphic analysis and the assessment of college-level introductory biology textbooks

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CREATING A FRAMEWORK FOR SYSTEMS-BASED GRAPHIC ANALYSIS AND THE ASSESSMENT OF COLLEGE-LEVEL INTRODUCTORY BIOLOGY TEXTBOOKS

A Dissertation

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M.A., University of Nebraska - Lincoln, 2000
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I would like to dedicate this dissertation to my father, Cormell, who consistently urged and encouraged me to further my education. Being the first in his family to achieve a high school diploma he then continued on to earn his Bachelors degree and then his Masters degree and finally his Ph.D. Knowledge of his uphill struggle to advance his education has helped inspire me to work towards earning my own Ph.D. Although I wish he were here to share this accomplishment with me, I still hold his memory as inspiration for now and as fuel to help propel me towards future goals and achievements.

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Abstract

Ecological literacy in students has become an increasing concern for educators. Mounting environmental problems along with a growing amount of nature deficit disorder seen in children and adults alike provides the impetus for research in this area. Since many college biology classes are modeled around the same style and emphasis found in the textbooks used for those courses, this provided an avenue for an examination of these materials. This research involved the selection of five popular introductory, college-level biology textbooks for analysis. Three rubrics were created to assess the graphical components of the introductory and ecology chapters in each textbook. The Systems-based Rubric (SR) was created to quantitatively assess the systems-based components of each graphic. The Tuftian Rubric (TR) was created to assess how well graphics comply with Tuftian rules of good graphics. The Ethnographic Systems-based Rubric (ESR) was created to qualitatively assess the systems-based nature of each graphic. The results of this analysis revealed that all of the textbooks examined, based upon analyzed graphics, could be classified as strongly Tuftian in nature. The results of this analysis also suggested that none of the textbooks assessed could be quantitative nor could they be qualitatively classified as strongly systems-based. Even when examining individual chapters of each book, all of the chapters were classified quantitatively and qualitatively as primarily reductionistic.

Chapter 1 Introduction to Ecological Literacy

In this introductory chapter, I will highlight a number of issues surrounding ecological literacy in the United States (U.S). I will explore why a better understanding of our environmental status is increasing becoming a more pressing area of concern. We have become more consumptive as a country even with current environmental education efforts. Many experts, like Speth (2010), have even noted on our growing consumption problems. Even when compared to other countries the U.S. seems to rate poorly in its environmental awareness. Through this introductory chapter I examine some of these issues and offer my hypothesis and predictions for developing a means of assessing environmental literacy and systems-based thinking in post-secondary education.

Statement of the Problem

During the past two decades U.S. citizens have been made aware of increasing environmental problems and seeing our country is a large contributor to those problems. Sustainability has become a widely used word even if many do not truly understand the meaning. Fitjof Capra has contributed heavily to the development of the deep ecology movement and furthered understanding of systems-based teaching. Capra has written several internationally acclaimed science education books including, *The Tao of Physics (1975), The Web of Life (1996), The Hidden Connections (2002)*, and *The Science of Leonardo (2007).* Capra is also a cofounder of The Center for Ecoliteracy in Berkeley, California. When describing ecological literacy, Capra elegantly captured the meaning of sustainability in this quote from Lester Brown of the Worldwatch Institute, "A sustainable society is one that satisfies its needs without diminishing the prospects of future generations" (Capra, 1996, p. 4). Sustainability is growing as a new standard for U.S. and global societies and has received increasing attention in formal education.

Capra suggests that the U.S. is in need of a major paradigm shift (Capra, 1996). He prescribes a movement away from more traditional approaches towards the teaching and understanding of science promoted largely by Descartes and Newton (Capra, 1996). Descartes has widely shaped the face of science education by promoting a mechanistic and reductionist view of life properties (Capra, 1996). Descartes' reductionist view of life supports the idea that living things can be best understood by breaking them down into smaller and smaller parts (Capra, 1996). Reductionist thinking follows the idea that parts always equal the whole (Capra, 1996). Similarly, mechanistic thinking describes living systems in the same fashion as machines, breaking apart into pieces and putting back together would produce the same result. These ideas are contrary to the type of understanding promoted by Capra and other subscribers to the deep ecology movement feel that the sum is greater than the parts.

Capra promotes a holistic view of living systems and ultimately an ecological view of living things. Capra believes that life cannot be divorced of the environment in which it inhabits, to do so would leave one with an unbalanced understanding of living things (Capra, 1996). By incorporating all of the parts of a living thing and the environment in which it occurs one comes away with a more complete understanding (Capra, 1996). Ultimately what follows with this systems-based view of living things is not only a better understanding of the individual life forms but also how they are affected and how they affect the environments in which they live. Capra and many other ecologists feel that systems-based teaching is the key to producing environmentally literate students (Center for Ecoliteracy, 2004).

Systems-based ecological thinking requires a shift from an anthropocentric view to a more ecological view (Capra, 1996). Capra defines systems-based ecological thinking as that that encourages looking at life by means of whole systems and not just independent parts. Capra also feel that humans can no longer be placed outside or on the top of a hierarchical view of living things. Humans need to be included in a view of the biosphere, showing how they affect and can be affected by environmental factors. These features are also promoted through systems-based teaching and can help develop ecological literacy.

Ecological literacy is becoming an issue of increasing importance for U.S. citizens and people around the world as we begin to appreciate the escalating severity of many of our environmental problems over the past few decades. This is a major cause for concern and has prompted many to question how we become a more environmentally literate society.

Growing concern over environmental literacy is highlighted in this statement from the Advisory Committee for Environmental Research and Education (Coyle, 2005), which sums up the current problem and what should be a future focus,

> In the coming decades, the public will more frequently be called upon to understand complex environmental issues, assess risk, evaluate proposed environmental plans and understand how individual decisions affect the environment at local and global scales...[This will require a] concerted and systematic approach to environmental education grounded in a broad and deep research base that offers a compelling invitation to lifelong learning. (Coyle, 2005, p. ii).

This statement highlights how pressing the environmental literacy problem is and begs to be addressed by the academic and educational community.

My personal assessment is that most students leave formal education with low levels of environmental literacy. The urgency of fostering environmental literacy compels all science educators to respond to this deficiency. If nothing else, educators should consider giving environmental education greater attention for the sake of better preparing students for dealing with real-world problems. As the worldwide state of the environment continues to decline, it behooves educators to look more seriously at further incorporating environmental education into traditional core curriculum. Further justification is shown in the U.S. public that is overwhelmingly interested in including environmental education as a part of formal and informal education for children and even for adults (Coyle, 2005).

Background and Need of Ecological Literacy

With increased environmental literacy comes an increased understanding of interconnections within living systems which is the foundation of ecological literacy. Likewise, better appreciation of the complexity found in the relationships of living systems can relate to deepening environmental literacy. Will Steffen, Executive Director of the Australian National University (ANU) Climate Change Institute, has created a flow chart (Figure 1) that demonstrates the scope, degree, and interactive nature of human alteration of the biosphere (Steffen, 2005).   This figure shows the connections between increases in human populations and how this can ultimately lead to greater resource use and loss of biodiversity. Ecosystem health is frequently gauged by measuring an area's biodiversity, including the species' richness and evenness. Overall humans can positively or negatively affect the health of the environment. Through summative data such as this, we can see that there is still a great need to produce ecologically literate and conscientious adults.

Figure 1 illustrates the interactive nature of human alteration on the biosphere and how that environmental alteration may also affect human health, economy, and recreation. This interaction between humans and the environment has resulted in environmental degradation. Steffen has worked to assemble environmental data from a multitude of sources and create a

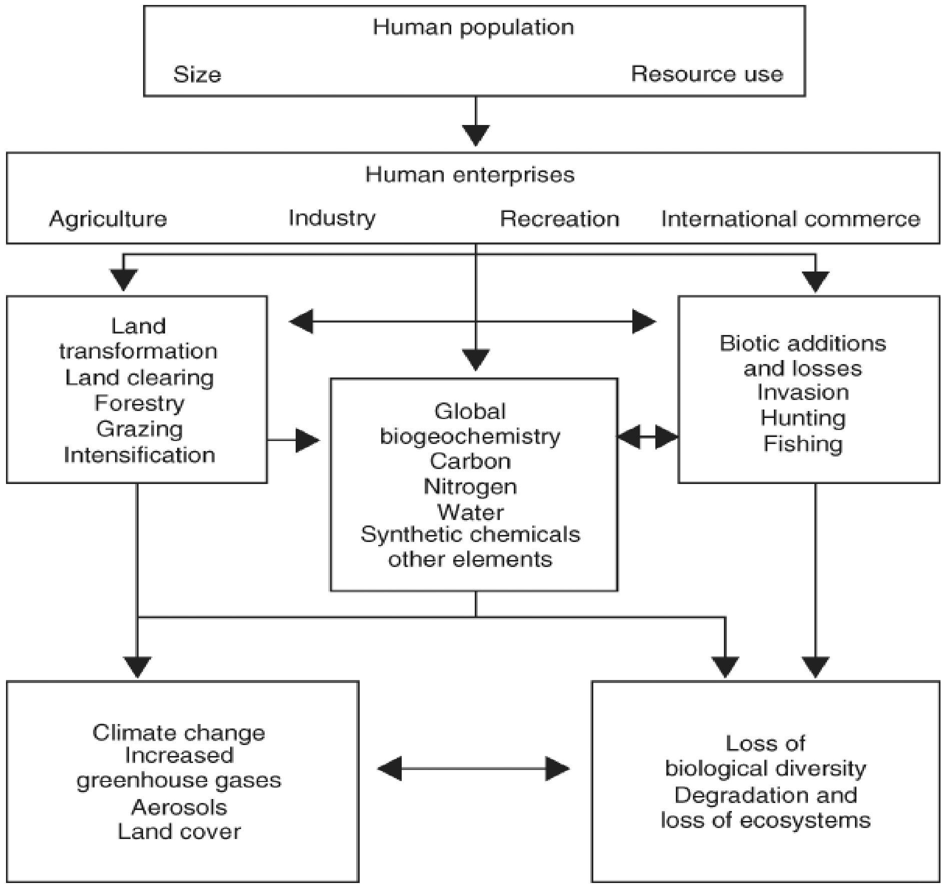

Figure 1. Flow chart of human alteration of the biosphere. W. Steffen, 2010, "Observed trends in Earth System behavior", *WIREs Clim Change*. Reprinted with permission.

number for illustrative graphs dramatically showing human-induced impact to the environment (Figure 2). The data reveals significant changes in the rate of human activities since the Industrial Revolution, which began in 1750. These graphs expose sharp, dramatic changes in human activity that suggests unprecedented changes to the environment (Steffen, 2010). Of particular interest is the sharp increase in human population around the 1950's, which corresponds with increases in land transformation, consumption, and exploitation of natural resources. The increase in water use and fertilizer use also correlates with increases in population, placing a further drain on the natural resources and promoting imbalances in functioning ecosystems.

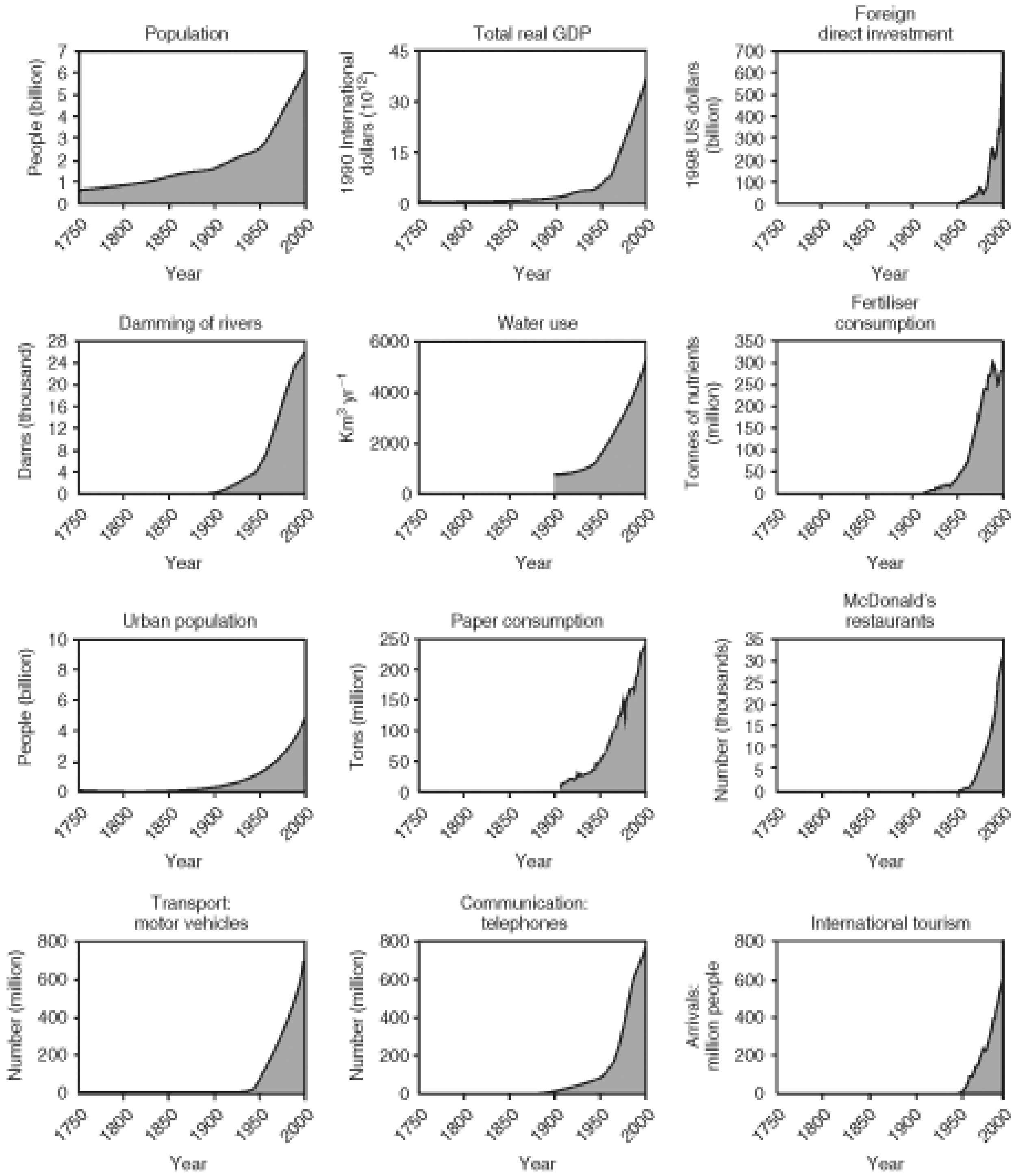

Figure 2. Changes in rates of human activities. W. Steffen, 2010, "Observed trends in Earth System behavior" *WIREs Clim Change*, 1: 428-449. Reprinted with permission.

Steffen has also compiled information about global changes to the environment that can be linked to human activity (Figure 3) (Steffen, 2010). Figure 3 (a) discloses a dramatic increase in CO_2 concentration levels since 1750. This increase correlates with the Industrial Revolution of 1750. Increases in CO_2 are causally linked to global climate change. The graphs shown in Figure 3 also expose increases in other greenhouse gasses including N_2O and CH_4 which are implicated in climate change. These graphs also show an increase in worldwide extinction rates and amount of exploited ocean systems.

The current state of the environment has recently been described in vivid detail by Dr. James Speth, Esq. during the 2010 10th Annual John H. Chafee Memorial Lecture on Science and the Environment (Speth, 2010):

> Here at home, despite four decades of environmental effort, we are losing 6,000 acres of open space every day and 100,000 acres of wetlands every year. Since 1982 we have paved or otherwise developed an area the size of New York State. Forty percent of U.S. fish species are threatened with extinction, a third of amphibians, 20 percent of birds and mammals. Since the first Earth Day in 1970 we have increased the miles of paved roads by 50 percent and tripled the total miles driven. Solid waste generated per person is up 33 percent since 1970. Manicured mountains of trash are proliferating around our cities. Half our lakes and a third of our rivers still fail to meet the fishable and swimmable standard that the Clean Water Act said should be met by 1983 (Speth, 2010, p. 7-8).

Speth addresses how the environment is not solely an issue for the U.S. Global problems beg for intervention and the U.S., being wealthy and powerful, stands to set an example. Likewise, these issues are not just problem of one nation, worldwide problems benefit from worldwide answers. Here he confirms more startling statistics:

> Half the world's tropical and temperate forests are now gone. The rate of deforestation in the tropics continues at about an acre a second, and has been for decades. Half the planet's wetlands are gone. An estimated 90 percent of the large predator fish are gone, and 75 percent of marine fisheries are now overfished or fished to capacity. Almost half of the world's corals are either lost or severely threatened. Species are disappearing at rates about 1,000 times faster than normal. The planet has not seen such a spasm of extinction in 65 million years, since the dinosaurs disappeared. (Speth, 2010, p. 7-8).

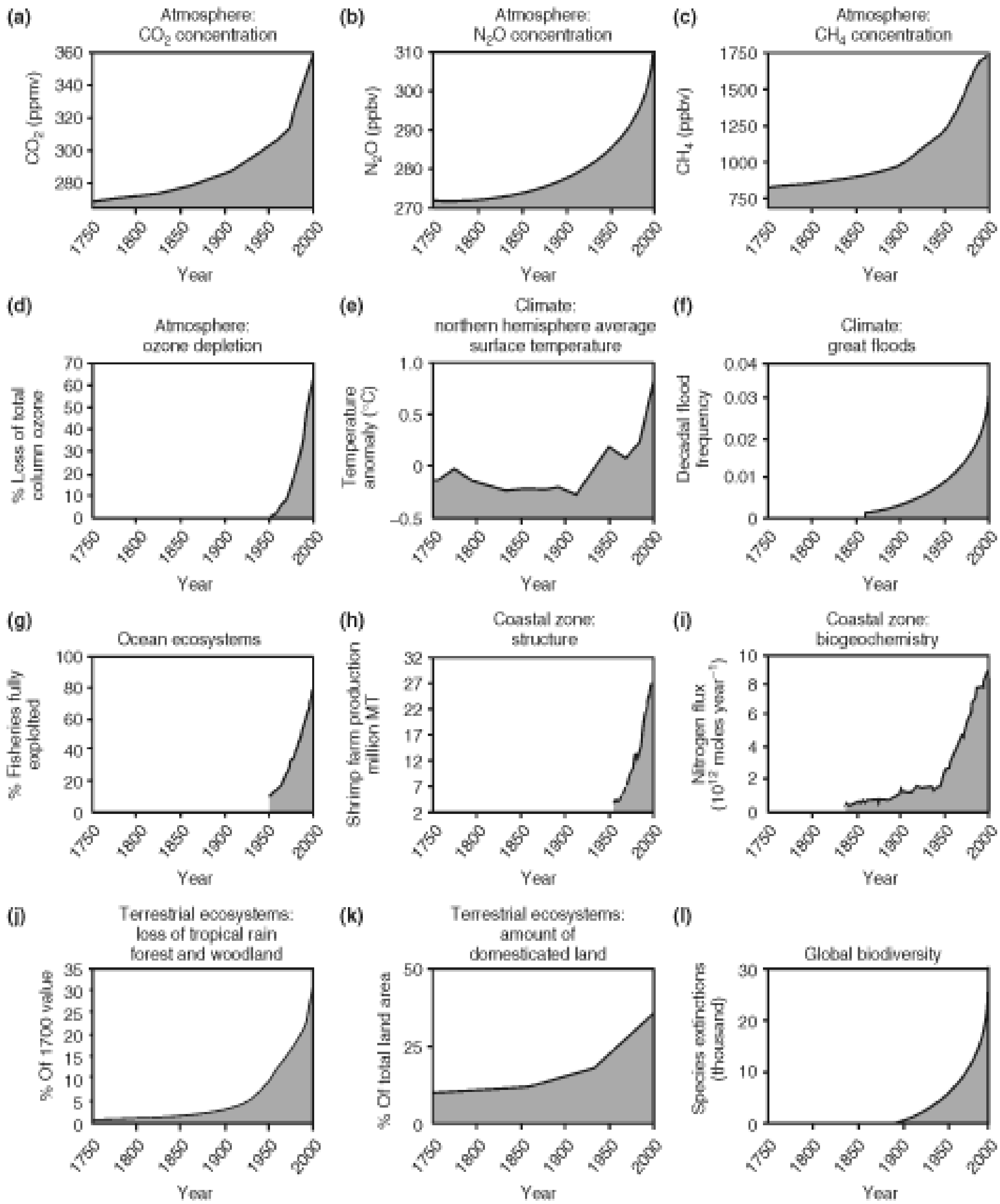

Figure 3. Global changes to the environment that can be linked to human activity. W. Steffen, 2010, "Observed trends in Earth System behavior" *WIREs Clim Change*, 1: 428-449. Reprinted with permission.

Speth further describes the uncontrolled and continued build up of greenhouse gasses even despite 30 years worth of warnings against these actions (2010). He also references the growing dead zones in the world's oceans, just like the one Louisianans experience every summer in the Gulf of Mexico (Rabalais, Turner, and Wiseman, 2002). Speth also forecasts water shortages and most major rivers running dry as a direct result of human over-production and over-consumption (2010). Despite treaties, laws, and warnings enacted as attempts to curb these problems, they continue to increase . Clearly, given the information presented by Steffen (2005) and Speth's keen observations and bleak assessments (2010), something must be done to better educate our growing population as to why we should care about these issues. Caring about an issue is an important first step. A second vital step is to figure out what can be done to change our ways and preserve as much as we can of this environment for future generations.

The excerpts from Speth's address lend even further support of an increasing need for formal environmental education. A number of other researchers, including Harris (1997), Yin (2006), and Speth (2010), have highlighted the highly consumptive trends of the U.S. as compared to other urbanized nations. These trends are even more pronounced when comparing the usage rates of the U.S. to those seen in other economically similar countries. The average U.S. citizen has little idea of how consumptive our culture has become and the dramatic affect that lifestyle has had upon our environment (Yin, 2006).

Even though the U.S. only represents five percent of the world's overall population, we consume more than 25 percent of all the world's natural resources (Yin, 2006). In the last 50 years, those of us living in the U.S. have seen number of changes in lifestyles. We have become more and more wasteful and have continued to use far more resources than any other industrialized or pre-industrialized nation (Harris, 1997; Yin, 2006). In the last 50 years we have seen the size of U.S. homes more than double from an average size of 983 square feet to now an average of 2,349 square feet (Yin, 2006). The annual number of miles driven by U.S. citizens has also increased by nearly six and a half times what it was in 1950 (Yin, 2006). And while the average number of people per U.S. household has declined, the average number of vehicles per U.S. household has risen (Yin, 2006). Even though some countries far outnumber the U.S. in terms of population, the U.S. still boasts a higher number of vehicles. For example, China averages 12 vehicles per every 1,000 people while the U.S. averages 779 vehicles for every 1,000 people (Yin, 2006). Lastly, U.S. citizens also use 75 percent more water than other industrialized nations, again illustrating just how consumptive the lifestyles in the U.S. have become in the last 50 years (Yin, 2006).

Even in light of all of this environmental information, many researchers and educators claim that our public knows very little about the state of the environment. Unfortunately, most citizens living in the U.S. believe that they know more about the environment than they actually do (Coyle, 2005). In fact, less than one to two percent of the population living in the U.S. could be classified as truly "environmentally literate" and only about 12 percent of the population can pass a basic energy awareness quiz (Coyle, 2005). To add to the problem, there is an abundance of old, outdated misinformation in existence about environmental topics (Coyle, 2005). According to Coyle, about 80 percent of those who reside in the U.S. are still heavily influenced by incorrect or outdated environmental myths. Further, most of the environmental information that is acquired, including by children, is obtained directly from the media. For instance, Coyle posits that approximately 83 percent of environmental information in the U.S. is obtained through the media and not formal education means (2005).

Research Rationale

These statistics have not improved over the past few years, suggesting that informal and formal education efforts to address these deficits have not been particularly successful. Additionally, younger generations being assessed on their level of environmental awareness do not score any better than older generations (Coyle, 2005). Coyle finds, though, a strong correlation between levels of environmental awareness with levels of environmental action (2005). This suggests the more environmentally literate a person becomes, then the more environmentally conscious their actions will be. Therefore, environmental literacy is a main goal to strive toward in educating our children and adults alike and by meeting this goal the number of more environmentally conscientious adults will increase over time.

This is the point where environmental education needs to be the most active in order to be the most impactful. Not only do researchers feel that environmental education is necessary as a core subject in schools but the U.S. public widely agrees. The most recent National Environmental Education Foundation (NEETF)/Roper research indicates that 95 percent of Americans think that environmental education should be a part of formal education in schools (Coyle, 2005).

In this vein, what exactly constitutes environmental education and what kind of benefits can we expect from its incorporation into formal education? Typically in the past, what has occurred is to give out environmental *information* as opposed to actually *educating* our youth and the public about the environment (Coyle, 2005). Environmental education requires active involvement with the environment, and environmental education takes time to develop and carry out (Coyle, 2005).

The No Child Left Inside Foundation (NCLI) (2007) has defined environmental education as:

> The study of the relationships and interactions between natural and human systems. It is interdisciplinary, combining aspects of natural sciences such as ecology and geography with aspects of social sciences such as economics, law, and public health. It is hands-on, student-centered, inquiry-driven, and relevant to students' everyday lives (NCLI, 2007)

The NCLI Foundation (2007) notes that children tend to gravitate towards subjects that are environmentally related, finding 40 percent of all science fair projects relating directly to the environment and more than 50 percent of community service projects also related to the environment. Environmental education is rapidly becoming a discipline area within science that needs to be more directly addressed through formal education beginning in elementary schools and continuing up through post-secondary schooling. The NCLI Foundation (2007) has also detailed three primary benefits of integrating environmental education into the sciences and throughout the curriculum. Using a systems-based, or a more holistic view is key to seeing such positive changes in the classroom. Although there are other direct and indirect benefits to environmental education, and even more benefits when instilling a systems-based view into the curriculum, the following are primary benefits (Center for Ecoliteracy, 2004; Coyle 2005; Klemow, 1991; NCLI Foundation, 2007; Orr, 1992):

- Environmental education has a positive impact on student achievement in other core subjects including math, reading, social studies, and other sciences. These increases in student achievement have been shown to be statistically measureable when environmental education is incorporated across the curriculum.

- Field experiences help promote healthy lifestyles and encourage greater levels of activity in children and adults. Outdoor classes and activities can help prevent obesity especially in children and may help lessen or eliminate the effects of attention-deficit disorder.
- Environmental education provides tools for a 21st century workforce. Environmental education helps students begin to understand the environmental problems they will be inheriting and the tools to make lifestyle changes to ensure a more sustainable future. Business leaders are more and more looking for workers and leaders who are concerned and knowledgeable about sustainability. Environmental education is interdisciplinary in focus and incorporates the economy, the environment and social equity to better prepare students for real-world challenges.

Recently, educational researchers have shown that environmental education and field-based experiences have been greatly reduced and even eliminated in some instances in favor of a more traditional focus in core curriculum (NCLI Foundation, 2007). As a direct result of the No Child Left Behind Act (NCLB) (2001), many teachers have been strongly pressured to devote more class time and effort to subjects that most frequently appear on standardized tests, i.e. reading, math and language arts. This increasingly narrow focus on standardized testing and increasing accountability in these three subject areas has also taken its toll on subjects that do not appear on these tests, such as science in general, social studies, and environmental education (Coyle, 2005; NCLI Foundation, 2007).

With the development of the NCLB act, education has also seen trend in moving away from the sciences and in particular, environmental studies. This has prompted some researchers, such as Coyle (2005), to suggest methods of assessment and even suggested standards for attempting to meet ecological awareness and literacy goals (Center for Ecoliteracy, 2004; Coyle, 2005; Klemow, 1991; Orr ,1992). In 2003 the National Council for Science and the Environment (NCSE) convened to create the report, "Recommendations for Education for a Sustainable and Secure Future" (NCSE, 2003). The purpose of this report was to emphasize the necessity of educating our youth for future sustainability. The document reports that all recent college graduates should possess the following skills:

- The knowledge to comprehend linkages among all living things, and their dependency on each other as well as the physical environment;
- The understanding for basic principles that govern natural systems and the ability to apply this knowledge to the limits to, and major factors associated with, Earth's capacity to sustain life;
- The ability to cross the boundaries of very diverse disciplines, including the understanding for cultural, economic, and political forces both past and present that affect attitudes and decision making about natural environments based upon science and technology understanding;
- The skills to better understand connections between science/technology and the natural/cultural environments;
- The talent for seeing "the big picture" in employing scientific method and technology as organizing tools to enhance a community's capacity for using local assets to build sustainable communities;
- The competence to think at a level where one can integrate scientific knowledge, economic and political realities, historical and cultural experiences, and moral, philosophical, and aesthetic values;

- The skills to engage in scientifically, socially, and culturally informed dialogue on environmental issues in communities in which the professional works and lives;
- The respect for the “public way of knowing” as well as the “expert way of knowing”; and
- The understanding for how people organize as family, community, etc., and how activities used to meet needs affect societal health, environment, and quality of life for present and future generations (NCSE, 2003).

There are several recurrent themes in the NCSE recommendations. Understanding relationships and interconnections appears to be a key point to helping students develop into environmentally responsible adults. There also seems to be an emphasis on understanding and integration of diverse areas of expertise. Engagement with civil and political areas complements a person's development into a environmentally literate and responsible adult. Considering some of the goals that educators have for students in the areas of environmental and ecological literacy, has lead me to consider all of the factors that might influence that outcome.

Research Questions

For the past nine years I have been teaching college-level biology at the freshmen, sophomore, junior, and senior level. Our Lady of Holy Cross College, where I teach, is a small, Catholic, four-year college in the greater New Orleans metroplex that has a heavy emphasis on professional majors such as education, counseling, nursing, and allied health. Even with this emphasis, general biology is considered core curriculum for most majors at the college. Exceptions to this are nursing majors who are not required to take general biology.

Over the years, I have experienced a surprisingly low level of environmental awareness in my students, and even fewer of my students have shown environmental literacy. Based on my experiences teaching at the collegiate level, I believe that as students learn more about interconnections in biologically based systems, the more likely they are to exhibit knowledge of environmental literacy and in turn, embrace environmental action. Systems-based biology is one key to helping students to relate more abstract, reductionist ideas as they are typically presented in classrooms more directly to the environments in which they live. Therefore, ecological literacy can be viewed as a starting place for helping to produce students with a real world understanding of environmental problems.

My assumption, based on personal experience and review of literature, is that our current, common, methods used to educate college undergraduates do very little to increase or help develop ecologically literate adults. To better explore this assumption, I propose to examine a sample of popular college-level biology textbook chapters for content that shows a systems-based view and incorporates an interactive view of humans and their place within the biosphere. Many times, textbooks can set the tone for a class, guiding lesson plans, and other curricular decisions. Systems-based biology needs to start with tools that appropriately incorporate those ideas and convey them to their audience. To start by assessing current textbooks we can then begin address the level of systems-based biological understanding in students and additionally the level of understanding in instructors who use those textbooks as well.

In essence, we need to look past traditional means of educating our youth. Future generations will depend more and more on a realistic understanding of how the environment affects human population and how human usage in turn can affect the environment. Although educators have harbored the notion that students emerge from post secondary education as well rounded adults ready to take on the current challenges of the world, some studies have indicated otherwise (Wayne, 2008). Reliable tools, such as textbooks, that present a systems-based view within the biology classroom may be an important first step to better comprehend how well students develop an understanding of the multi-faceted, interconnections of ecosystems.

I believe that textbooks are critical to an instructor for the development of a course and that it is essential for instructors to have access to and to utilize textbooks that can encourage the development of systems-based thinking, ecological literacy, and ultimately environmental action in students. My goal of this research is to develop a clear picture of how much our textbooks can help advance the development of ecological literacy in our students. I propose the following research questions:

- What is the typical amount of graphic content within a sample of collegiate introductory biology textbooks that uses systems-based thinking versus reductionistic thinking?
- How do collegiate introductory biology textbooks use reader-centered graphics that correspond to classic Tuftian principles?
- How do select collegiate introductory biology textbooks utilize a mixture of reductionistic thinking and systems-based thinking through graphics?

Methods of Graphical Content Analysis

The focus of my research on ecological literacy in the college classroom and particularly how that literacy can be better developed through the use of textbook graphics that promote systems-based thinking. My intention is to develop a framework for assessing textbook graphics with regard to the incorporation of systems-based principles. I propose to conduct a content analysis of the graphical content of a sample of several college-level introductory biology textbooks. For this analysis I have selected a representative sample of textbooks based upon ranking of online textbook sales. This first part of my analysis involves a quantitative assessment of these textbooks graphics using two rubrics I have developed using guidelines as outlined by Stevens and Levi (2004).

The first rubric, the Systems Rubric (SR) is based on a systems perspective (see Appendix B) and is centered on the six categories that represent the most essential principles of Fritjof Capra (2004) and deep ecology: networks, nested systems, cycles, flows, development, and dynamic balance. Based on this analysis, either a primarily reductionist approach or a systems-based approach will be highlighted for each graphic. I analyzed all graphics including tables, illustrations, and pictures in the selected textbook chapters, following those as identified by Chiappetta, Fillman and Sethna (1991b/2004) as units that should and should not be included in a content analysis of science textbooks.

In addition to analyzing for Capra's essential principles I examined these graphics for any aspects that may align or violate Tufte's graphics guidelines (Tufte, 1990, 1997, 2001, 2006). Tufte emphasizes that graphics showing data should utilize the following guidelines: show the data, avoid distortion, maximize data ink, avoid chart junk, have a clear purpose, clarify large data sets, using multivariate displays of data, use data along with written descriptions, and reveal the data in layers to create depth. Analyzing graphics for Tuftian principles will help illustrate how "reader friendly" introductory biology textbooks may be to college students. I have developed a second rubric, the Tuftian Rubric (TR) (see Appendix C), also using the guidelines of Stevens and Levi (2004) and focusing on the principles of Tufte. I used this rubric when assessing each of the graphics in these selected textbook chapters.

For this study, I also incorporated a qualitative aspect to this content analysis by following methods as proposed by Altheide (1996). Altheide describes ethnographic content analysis as a reflexive means of analyzing content that maintains a level of flexibility while still maintaining a systematic and analytical approach (1996). Altheide's approach to ethnographic content analysis is described as, "categories and variables initially guide the study, but others are allowed and expected to emerge throughout the study, including an orientation toward constant discovery and constant comparison of relevant situations, settings, styles, images, meanings and nuances" (1996, p. 16). By using this approach graphical content will be identified and classified into specific categories, such as, directly systems-based, indirectly systems-based, indirectly reductionistic, directly reductionistic. The Ethnographic Systems-based Rubric (ESR) was created to address this level of assessment (see Appendix D).

A graphic that ranked as directly systems-based in this foundation overtly displayed human empathy for other life forms. Humans would have been shown as fully integrated within an ecosystem. Indirectly systems-based implied this empathy but not show it explicitly. Indirectly reductionistic might have suggested that humans are separate without directly displaying this reductionistic concept. Directly reductionistic made no attempt to show any empathy to other living things and clearly displayed humans as separate and above their ecosystem.

Chapter 2 History of Science Education and Ecological Literacy in the United States

In order to fully understand the issue of ecological literacy, an examination of the history of science teaching and the development of ecology as a recognized field of study will be presented first. Richard Duschl (1990) has made significant contributions to the understanding of the nature of science and the importance of including scientific theories in science education. A discussion of the current state of environmental literacy and science education in the United States will follow. Lastly, I will recount the development of the deep ecology movement and how systems based teaching can play a vital role in the development of more ecologically literate adults through formal higher education. The graphic organizer (Figure 4) illustrates the connections between ideas and authors discussed in this section.

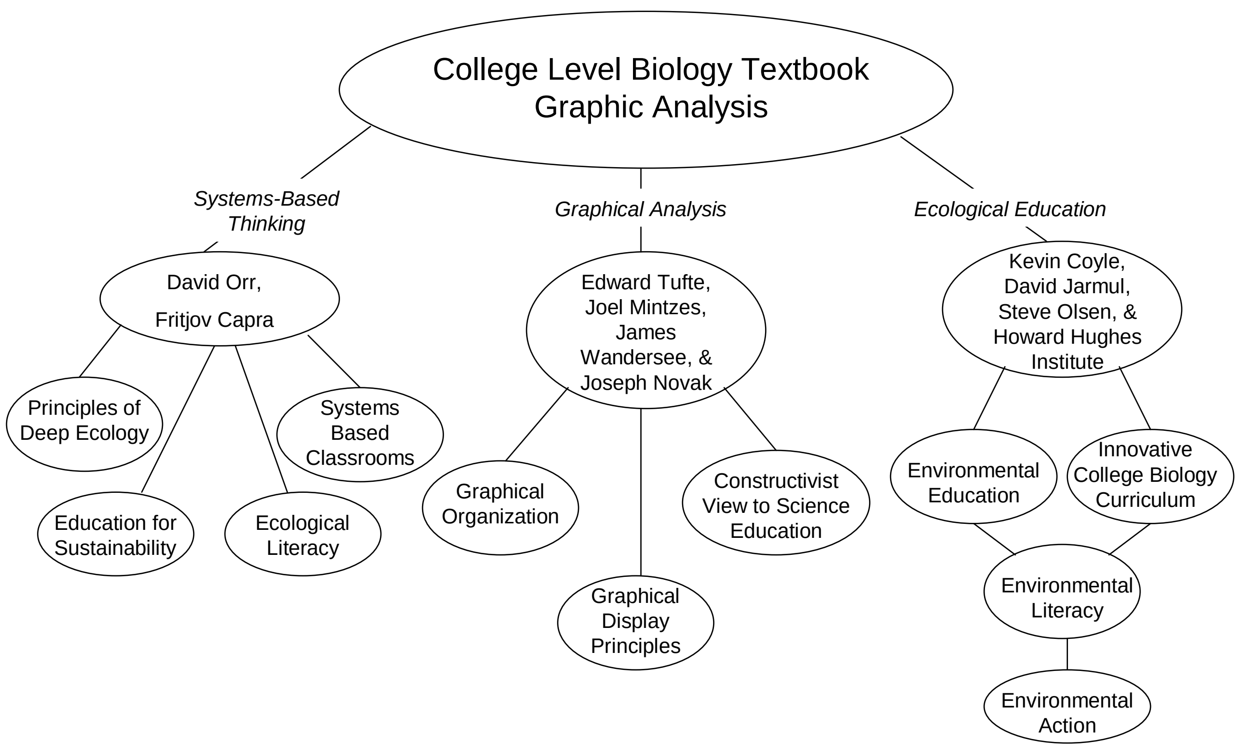

Figure 4. Organization of college textbook graphical analysis for systems-based thinking

A History of Science Teaching

Student achievement is almost always considered a major issue when it comes to any college-level course work (Duschl, 1990). In education, the sciences are often plagued with instructors who are reluctant to change, disinterested students, and a lack of information in a balanced fashion about the many options that exist when it comes to improving performance (Choi & Ramsey, 2010; Southerland, Sowell, & Enderle, 2011). Instructors have an obligation to stay abreast of all the current findings on teaching and learning techniques. Likewise, college students should remain open to unfamiliar styles that may improve their own knowledge acquisition.

Based upon my own experiences in the classroom and from personal communication with other science professors, many times college professors instructing freshmen level science courses run into the same issues semester after semester: poor attendance, low test grades, and high drop and failure rates. These phenomena are seen more often in non-majors taking these courses than in biology majors. Science educators have likened learning science, and biology in particular, to that of learning a foreign language. Some evidence has suggested that students are introduced to more new words per week in a science class, than would even be recommended for a foreign language class (Groves, 1995). Additionally, much of the vocabulary in a freshmen science class is abstract to the student and bears no clear relationship to real-world ideas. Researchers have suggested that contextualizing the material in order to make the vocabulary more concrete to the reader is one way of improving retention (Hillocks, 1981; Miller & Cheetham, 1990; Mintzes, Wandersee, & Novak, 2005a).

Science teaching techniques and theories

According to Miller & Cheetham (1990), there is a need for more research investigating innovative teaching or novel study techniques for college freshmen biology. Additionally, most college science instructors have very little to no training in teaching techniques or learning styles. These are areas that have been not only neglected in research but have been somewhat resistant to change. These types of studies are novel to the field because little research has been conducted with attempts to improve performance in the college-level biology classroom (Miller & Cheetham, 1990).

The Dual-Coding Theory by Paivio (1986) postulates that humans learn through different coding mechanisms that are naturally distinct. He suggests that verbal information and retention can be strengthened by linking it with corresponding visual information. The Dual-Coding Theory postulates that both visual and verbal information are processed differently and along distinct channels with the human mind creating separate representations for information processed in each channel. Both visual and verbal codes for representing information are used to organize incoming information into knowledge that can be acted upon, stored, and retrieved for subsequent use.

Despite this theory not being universally or completely accepted in the scientific community, alternate theories have been proposed by other educational researchers that coincide with the basis of the Dual-Coding Theory (Sadoski, Paivio, & Goetz, 1991). One example of this is shown through research by Hackney and Ward (2002), who claim that utilizing roundhouse diagrams to get students to develop more critical thinking about scientific processes is beneficial. Humphreys has also conducted research that focuses on using the dual-coding theory to foster and maintain visual mental images of verbal information (Humphreys, 1998).

In *Student Successes With Thinking Maps*, David Hyerle (2011) states that using the eight Thinking Maps promote metacognition and continuous cognitive development for students across their academic careers, as well as adds an artistic and kinesthetic component for students who learn effectively with multiple intelligence (Hyerle, 2011). Lesson objectives can be covered in less time and with greater retention when using Thinking Maps, teachers can determine their students' background knowledge before teaching a unit or area of study, and student performance can be tracked over time in an accurate manner (Thinking Maps, Inc., 2011). Through his research, Hyerle (2011) also found that Thinking Maps help close the achievement gap, as they "can help students [below grade level] self-regulate their own learning and be more successful in the game of school because Thinking Maps serve as a device for mediating thinking, listening, speaking, reading, writing, problem solving, and acquiring new knowledge." The thought processes that educators hope to instill in students are represented similarly throughout the curricula, and integrated thinking and learning across disciplines is promoted (Thinking Maps, Inc., 2011).

In Villalon and Calvo's (2011) *Concept Maps as Cognitive Visualizations of Writing Assignments*, concept maps are discussed as a means of scaffolding university-aged students' ideas in writing, as well as their metacognitive skills. In their study, Villalon and Calvo evaluated a new Concept Map Mining tool, which was used in an "e-learning environment" that automatically generated maps using students' written work. The Concept Map Mining tool was used to look at a collection of annotated essays written by undergraduate college students (2011). Villalon and Calvo (2011) found that "Cognitive Visualizations [such as Concept Map Mining] provide quality feedback because they make the author's thinking visible, making explicit the mental model learners are using" (p. 23). Villalon and Calvo's (2011) study illustrates that the use of concept maps are beneficial to even the oldest of learners in a college setting, and although precise Thinking Maps were not used in this study, the idea of a graphic organizer to “map out” thought processes is universal.

In *Thinking with Maps*, Elisabeth Camp (2007) investigates how individuals think and how thinking is related to language. She states that “…thinking in maps is substantively different from thinking in sentences” (p. 155). This concept supports Hyerle's (2011) idea that Thinking Maps possess an artistic and kinesthetic component, where students can feel free to express their ideas in a “drawing,” or map, instead of using complete written sentences. Thinking Maps support learners who thrive with the artistic and kinesthetic multiple intelligences of learning.

In a similar vein, Mintzes et al. (2005a), suggest a new way of viewing science education. Thus advocating, "quality over quantity, meaning over memorizing and understanding over awareness" (Mintzes, et al., 2005a, p. xix). This represents a stark departure from a style of science learning that has been in place for decades and promotes extensive rote memorization and very little effort to develop deeper learning in students. Mintzes et al. (2005a) suggest a variety of techniques for encouraging deeper understanding of science concepts in students. Graphic representation and creation of graphics, active student participation in the learning process, and the use of technology all can be seen as possible vehicles for true scientific understanding (Mintzes et al., 2005).

Supporting evidence for this model comes from research that indicates that memory for some verbal information is enhanced if a relevant visual is also presented or if the learner can imagine a visual image to go with the verbal information (Anderson and Bower, 1973). Likewise, visual information can often be enhanced when paired with relevant verbal information, whether real-world or imagined (Anderson and Bower, 1973). Verbal information when paired with an image, imagined or real, showed increased brain activation to process abstract words not easily paired with an image.

These types of research have led some researchers to suggest new ways of teaching and viewing college level biology. Gottfried, Hoots, Creek, Tamppari, Lord, & Sines (1993) created a review of college biology teaching based on Sigma Xi's "seven fundamental topics" for teaching biology. Based on these seven fundamental topics, they created a series of suggestions and ideas for improving biology teaching (Gottfried et al., 1993). By focusing on these essential topics of biology, educators are free to cover the issues with more depth (Gottfried et al., 1993). This method promotes greater retention of concepts and encourages more abstract conceptualization (Gottfried et al., 1993).

In tandem with the findings of Gottfried et al. (1993), Gess-Newsome, Southerland, Johnson, & Woodbury (2003) suggest possible reasons why instructional changes are difficult in college classrooms. In both of these studies, Gess-Newsome et al. (2003) and Gottfried (1993) focused on changes in attitudes of faculty teaching science, and in students' perception of science. These researchers highlight the absence of investigation that has been conducted on teaching biology at the college level (Gess-Newsome et al., 2003; Gottfried et al., 1993). Additionally, Michael and Modell have examined science teaching and found a great deal of inflexibility in applying new teaching techniques (2003).

Technology-based teaching

Other researchers have elected to examine the effects of technology on learning expectations in students. Christoph Lüthy (2000) illustrates how many students are now looking to the media and especially television as a major source of information. Lüthy presents an evaluation of how technology changes over time have influenced how students perceive the role of teachers and other sources of information (2000). Prior to the advent of rapid technology in information exchange, students viewed teachers as the ultimate source of knowledge and information (Lüthy, 2000). Currently, more students put faith in the television for gathering information rather than teachers or instructors (Lüthy, 2000). This affects students' expectations, attention and prior knowledge (Lüthy, 2000).

Educational researchers reveal varying degrees of success when examining the incorporation of technology into the classroom or as a study tool. Terry (1999) suggests using the internet as a teaching tool for college level biology courses. Terry's research provides examples and details of how this new technology has been and could be used in the classroom, especially for biology. Another instance of using technology in the biology class is credited to Sanger, Brecheisen, & Hynek (2001) who test the effectiveness of incorporating a computer program to demonstrate complex biological concepts such as diffusion and osmosis (Sanger et al., 2001). The application of technology to enhance science teaching seems to be effective and also tends to help overall understanding and long-term retention.

Other researchers focus on how students utilize mental models in grasping abstract concepts. Hegarty, Kriz, & Cate (2003) explore how animations might facilitate the learning of mechanical models for students using computer simulations. Interestingly, the animations did not seem to facilitate learning in this model any more than static figures (Hegarty et al., 2003). What seemed to improve learning the most was the addition of questions and interaction with the students upon presenting the animations or figures (Hegarty et al., 2003). When subjects were forced to manipulate the information presented, then their understanding deepened and greater retention followed (Hegarty et al., 2003).

Other research such as the work of VanLehn, Siler, Murray, Yamauchi, & Baggett (2003), explores student learning from another perspective. This research examined student learning as it is associated with tutoring techniques (VanLehn et al., 2003). Even when using numerous tutoring tactics, the students still only seems to advance in learning goals when they reached an impasse (VanLehn et al., 2003). This corroborates other researchers' findings that suggest that students can acquire information but true learning requires being forced to manipulate or actually use the information themselves. Not only does teaching frequently require adjusting to this issue, but student expectations may also need adjustments in order to get the most out of this learning style.

Much of the previous research on teaching and learning sciences encourages some professors to seek out new and novel ways to teach complex subjects. Miller and Cheetham (1990) suggest using more active learning approaches to the delivery of introductory biology. They use several different active learning styles including elimination of tests and lectures, integration of collaborative work, and presentation of findings. They found that these approaches work to involve students and improve learning.

David A. Kolb (1984) was instrumental in starting the trend towards more active learning styles, especially promoting its use in the science classroom. This trend requires a more integrative style and increased participation from students. This transition in teaching can also be viewed as a step away from the more mechanistic styles brought about by philosophers such as Descartes (Capra, 1996). While students tend to benefit from this active learning style with increased learning and retention it can still be a difficult shift for instructors taking time and effort to modify curriculum to fit these newer modes of instruction.

Active learning, especially in the sciences, has been gaining popularity with teachers at every level of education, from primary to post secondary education. Even in light of its gaining popularity some of drawbacks of active learning are described by Michael and Modell (2003) in their influential book, *Active Learning in Secondary and College Science Classrooms*. For example, when incorporating this new instructional method instructors will need to adjust the course content to insure coverage of all necessary information. Instructors may also need to alter current class plans and lectures to incorporate more active learning techniques (Michael & Modell, 2003).

Another potential pitfall of transitioning to an active learning style is that many students may resist due to limited experience in this technique (Michael & Modell, 2003). My personal experience in the classroom has shown that even when students benefit from active learning in that they seem to better understand and retain the information, most resist contributing to the class experience. Most students are more comfortable with a passive style of lecture and must be coaxed into active participation.

Furthermore, course evaluations that do not measure student learning or instructor skill but rather measure student satisfaction with a course may create a disincentive towards switching to active learning (Michael & Modell, 2003). If students are unfamiliar with a technique and feel initially uncomfortable using it that can cause them to rate these instructors more negatively than their peers. Evaluations such as these may be negatively impacted by a switch to a more active learning style.

Lastly, some instructors may shy away from the active learning style simply because they are fearful of moving to a different style or just reluctant to try something new. Additionally, instructors face possible criticism by colleagues who do not understand that the active style really does support greater learning and retention of the material in students. These final two critiques are probably the biggest impediments to advancing active learning in the classroom (Michael & Modell, 2003).

Many researchers feel that active learning is the best way to promote learning and retention, especially long term retention (Choi & Ramsey 2010; Gess-Newsome et al., 2003; Kolb, 1984; Michael & Modell, 2003; Mintzes et al., 2005a). Even though many researchers tend to agree on this as an excellent technique, many instructors still seem reluctant to convert to this style (Michael & Modell, 2003). Many of the above mentioned disadvantages are the reasons that instructors are slow to convert. Over time increased familiarity with active learning is most likely to increase its usage.

Research in the area of science teaching and learning at the college-level has been slowly increasing over the past few years (Jarmul, Olsen, & Howard Hughes Institute, 1996). The key to improving student achievement in these areas is simply being open to change and having a willingness to implement some of these ideas. Based on my own experience and personal communication, student expectations may also limit some of this transition; apathy, resistance, and fear are features that many college science instructors face every day when in the classroom setting. There is also a wide potential for further research in examining more direct links between instructional techniques in teaching science and student performance or achievement. A number of different factors could be incorporated and a variety of assessments utilized.

Restructuring Science Education

Richard Duschl has become widely known for his contributions to the field of science education. Duschl currently teaches as a Waterbury Chaired professor of secondary education at Penn State University (Duschl Webpage, 2013). His research focuses on epistemic learning environments and how student inquiry can supplement and develop this environment. Duschl's articles published in the *Journal of Research in Science Teaching* have won the JRST Award twice in 1989 and 2003 (Duschl Webpage, 2013). Duschl continues to push science educators to consider not only outcomes in students but the entire process of learning science.

Professor Richard Duschl's book, *Restructuring Science Education* (1990), has been influential in shaping science teaching. This book, and arguably his most influential work, Duschl emphasizes the importance of including the history of science in teaching any science related discipline. Teaching science this way, can greatly improve the quality of students produced from a traditional science program.

Bases of science education

Duschl begins his book with some background about science education. At times, educators get wrapped up in the details of the subject in which they are addressing that they may not remember to focus on the goals and background of the student body that they are teaching. The bases of science education, or rather, things to bear in mind when teaching in the sciences were some of the first things he discusses (1990).

According to Duschl, the main goal of science education is fairly straightforward: teach students what science knows and does not know, what it can and cannot do, and what we can and cannot expect from science (1990). Duschl discusses the methods used by science educators including elementary on up to post secondary. He claims that most educators, and textbooks in this country, tend to focus only on the first part of this goal: teach students what science knows. He postulates that this should only be a small part of the equation for science education (1990).

Educator background is also another important issue to remember when focusing on reforming science education. Most college-level science educators know a lot *of* science but not a lot *about* science. For example, many of these educators cover a section on how cells go through division, known as mitosis. Although most know all of the steps of mitosis and can illustrate the path each cell takes to replicate itself, very few know *how* we came to know that cells behave in this manner (Duschl 1990). Therefore, some educators may not be familiar with Walther Fleming and how he came to discover chromosomes and see how they behave during cell division. Even fewer will actually incorporate the trial and error process that scientists have gone through to answer some of these questions. In fact, there were dozens of other scientists who conducted research that furthered our understanding of cell structure and reproduction. Without this background scientists would not know things like where chromosomes are housed in the cell, how they relate to heredity, and how they behave throughout the cell cycle. Furthermore, the natural flexibility of science tends to be ignored allowing students to develop an idea of science being rigid and absolute (Duschl, 1990).

Teachers many times neglect to focus on the nature of science and history of science simply because they themselves were never taught it (Duschl, 1990). In order to use history of science in the classroom, teachers would need to be brought up to speed on the training that they may never have received. By and large, teachers teach the way they were taught. So restructuring how we teach science education will require not only curriculum changes but more teacher development in these neglected areas (Duschl, 1990).

In Duschl's book, he makes an excellent case in support of integrating nature of science and history of science into the science classroom, and even into other subjects. He suggests that by teaching the history of science teachers can better justify what scientists do (1990). He also notes that most science education textbooks completely ignore the discovery side of science. Duschl states this lack of discovery in the field of science can lead to a field of study that is epistemologically flat (1990). Students never get the full depth and complexity of how science and scientists work. Duschl's commentary and views (1990) help to add a new perspective to the field of science education textbooks.

In addition to integrating the nature of science and history of science, Duschl also recommends that teachers should model and structure their curriculum around theory development. Duschl recommends structuring curriculum around the development of theories wherein one can model the natural ebb and flow of science progression. Further, he claims that by teaching from an integrated stance, students learn that science is not comprised of a static, immutable fact base, but that science is about inquiry and change (Duschl, 1990).

Nature of science

One important theme of Duschl is clarifying the nature of science. The basic principles of the nature of science are as follows:

1. The standards used to assess the adequacy of scientific theories and explanations can change from one generation of scientists to another.
2. The standards used to judge theories at one time are not better or more correct than standards used at another time.
3. The standards used to assess scientific explanations are closely linked to the then-current beliefs of the scientific community. (Duschl, 1990, p. 5).

Duschl theorizes that, unfortunately, the typical non-scientist does not have a good understanding of the nature of science or theory development and therefore generally may have difficulty judging the legitimacy of scientific claims. Most people view science as fact, when in actuality most of science is based on theory (Duschl, 1990). Duschl suggests most also do not know that there are criteria that can be used to judge scientific theories. Finally, he advances that many acquire the belief, through science classes, that theories develop through a process of replacement instead of constant modification and evaluation (Duschl, 1990).

History of science education

The history of how we teach science in this country is marked by societal opinions and changes in political thought (Duschl, 1990). Before the 1960's, science was taught in a very straightforward manner. Most believed that only a select few people could ever really become scientists and therefore science classes should be taught primarily to them. This was the "science for scientists" period in science education history (Duschl, 1990). A growing concern that this method was insufficient to educate most of our student body followed. Science needed to be more accessible and available to all students, not just those who might end up in a science based career (Duschl, 1990).

During 1950 the United States saw the development of a major science funding body; The National Science Foundation (NSF) (Duschl, 1990). The purpose of NSF was to promote science, but in light of that goal, the funding of science education was also included. NSF's budget to funding science education research and curriculum development quickly increased over the next five years (Duschl, 1990, p 17). Linking research to curriculum development seemed like a logical pairing, but soon, some public and political outcry developed over suspected government regulated curriculum (Duschl, 1990). NSF began downgrading funding and support in these areas of curriculum development (Duschl, 1990).

It was not until the year 1956 did the United States see a great reversal in the area of science education (Duschl, 1990). In 1957 the Russians successfully launched the first satellite into space; Sputnik. This action propelled the U.S. to seriously rethink their position in the global race for scientific superiority (Duschl, 1990). Since then, funding to science education continues to increase but still continues to come under growing scrutiny (Duschl, 1990).

Today much of the spending in science education is focused on the development of high school science classes and curriculum. Still many have begun to realize that teachers are the key to quality education. Teacher development is just as important, or more so, than curriculum development (Duschl, 1990).

Unfortunately, politics and resultant governmental policies, such as the No Child Left Behind Law (2001), threaten to derail some of the progress that has been made in areas of science education. NCLB's narrow focus on standardized testing has forced many teachers to resort to 'teaching to the test'. Because of threats to withhold funding from low performing schools, administrators and teachers may feel that they have no other choice but to eliminate any "extra" subjects or exercises and to only teach material that is covered by standardized tests. Since math and reading skills are the primary focus of NCLB, science as well as other subjects may be underemphasized (No Child Left Inside Foundation, 2007).

Shifting focus of science education

Duschl's goal is to get science educators thinking about how we teach science and what we think is important to teach. Duschl emphasizes the two faces of science, the discovery face and the justification face (1990). The discovery face focuses on *how* we know science and the justification face focuses on *what* we know of science. Most science texts and courses focus on only one face of science. By only focusing on one face of science, we run the risk of creating students who do not understand the rationale of science and fail to view it as a complex, evolving subject.

Duschl recommends shifting our focus in science education so that students learn how scientists come to the conclusions that they do. Students also learn that science is constantly changing and riddled by periods of doubt and questioning. Science is built on consensus, or agreement, and what Duschl terms ‘dissensus’ or disgreement (1990). Using the development of theories in curriculum development can help achieve these goals (Duschl, 1990).

Traditionally, science education has simply ignored the malleable nature of science. When teaching science it should be more about “inquiry into inquiry” and less about the passing on of facts. Facts do not produce or provide understanding. If understanding is the goal then facts alone are insufficient, students need to learn the process of science to truly begin to understand and appreciate it (Duschl, 1990).

Rethinking theories

The simplest definition of a theory is that it is an explanation (Duschl, 1990). Theory can also be a combination of aims, thoughts and methods surrounding a particular question or set of questions (Duschl, 1990). Scientists define theory more specifically as an interconnected body of concepts that have been well supported through testing and retesting (Raven, Johnson, Mason, & Losos, 2010). Some ideas about theories hold true regardless of which of these definitions are used.

Important for students to know is that there are guidelines that can be used to help judge theories (Duschl, 1990). These guidelines as detailed by Duschl are as follows:

1. Not all theories are equal; some get more weight than others.
2. Theories can and will change, current scientific and societal beliefs can influence the acceptance, rejection or modification of a theory.
3. Theories are not typically replaced they undergo periods of consensus and dissensus.
4. There are guidelines that can be used to help judge the weight of a particular theory.
5. Theories can be traced through an evolution of changes through history, understanding this history can help give merit and validate potential future changes in scientific thinking (Duschl, 1990, p. 7).

Duschl (1990) indicated a hierarchy of scientific understanding based on theory development (Figure 5). Each feature below leads to the feature above it. The ultimate goal of the process of science education is thus, true scientific understanding. The question remains as to how well we meet this goal and how we can improve our means of obtaining it if we do not meet it. This hierarchy highlighted that scientific understanding is our ultimate goal. If the others do not lead to this then there is a breakdown in the system.

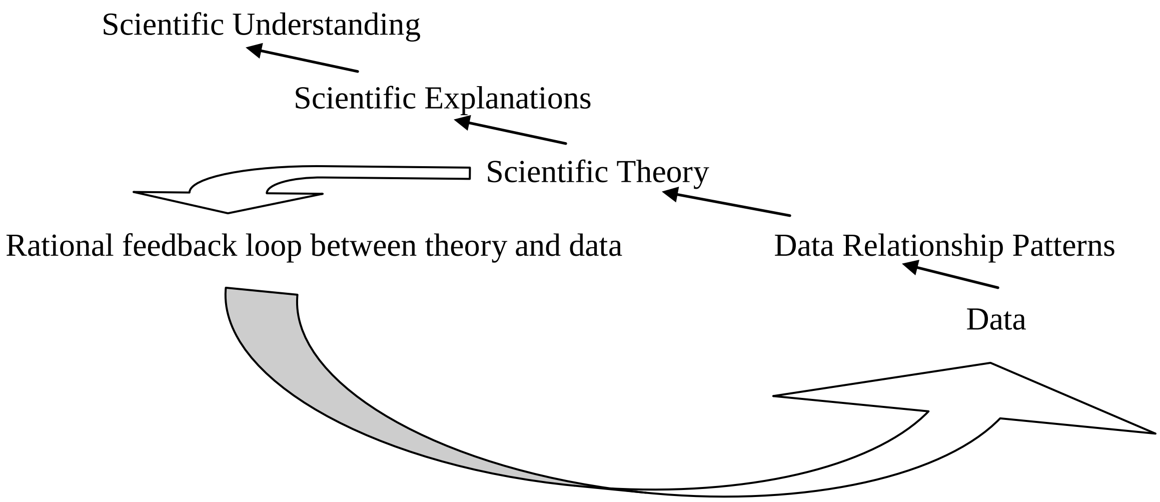

Figure 5. Hierarchy of scientific understanding. From *Restructuring Science Education*, by R. Duschl, 1990, New York, NY: Teachers College, Columbia University. Copyright 1990 by R. Duschl. Reprinted with permission.

Duschl also presents various ways to view scientific theories (Duschl, 1990). I especially like the idea of theories being placed into different levels of a ball. The center of the ball would contain theories of which we are most sure. This would be the core level, ideas that are well verified and supported. For example, the Laws of Thermodynamics could be placed here at this core level. The next level, toward the surface of the ball, would be considered the frontier level. Theories with solid grounding and much support but which still garner unanswered questions might go here. The Theory of Evolution could be placed here. The last level would be the outer covering of the ball or the skin. This is the fringe level. These are the newest, least verified ideas. Most of these new ideas will not make it to the next level, but all ideas start here. An idea, for instance, such as quark physics, might lie on the outer level of this ball. This ball analogy could be helpful in guiding students to effectively judge scientific information and come to more appropriate conclusions about the validity of each.

How this book has personally affected my thinking and teaching

Duschl's book was eye opening for me. His thinking and perspectives resonated with me regarding how teaching only a single face of science could produce students who doubt what we do as scientists. Many of my own students leave my classroom and my courses with more *of* science but not *about* science. Many still have no idea why we do the things we do and believe the things we believe as scientists. For example, some may know that when prescribed an antibiotic one should continue to take them and finish the treatment even after beginning to feel better. But many may not know the reason for that is to insure that all the harmful bacteria are killed and do not start to multiply into a resistant strain.

I also recognized, often in the middle of a lecture, that I teach exactly the way he says most science educators teach, the way I was taught. I think throughout my formal education I did learn a lot of the "what" questions in science and not very many "how" or even "why." Since reading this book I have become more determined to restructure my own curriculum and try to integrate more of the two faces of science into my courses. Some of my ideas about modifying my current course would include the following:

- Try to move away from "final form" teaching. Scientists go through many permutations of what is finally accepted as "theory." Teaching in a final form approach simply ignores all of the inquiry and questioning that are part of the development of science.
- Incorporate the nature of science and the history of science into all of my courses. Students can better appreciate why we think the way we do if they learn the process we used to arrive at those conclusions. For example spending more time discussing the

development of principles and theories discussed in a class, such as how the theory of evolution was arrived at by Charles Darwin instead of just describing the theory itself.

- Aim for meaningful learning. Breaking down complex subjects into more manageable pieces and then drawing complex connections to those pieces can lead to meaningful, lifelong learning for students.
- The dynamics of knowledge development are much like the dynamics of theory development, both make advances on a shifting methodological and phenomenological framework. By structuring course curriculum around scientific theory development one can begin to accomplish many of these aforementioned goals.

This was a very interesting and influential book that could have positive ramifications on the future development of science education. I hope to fully incorporate some of these ideas into my own teaching and research to help produce more well-rounded thoughtful science students.

A History of Ecology as a Science

Throughout history, humans have shown an interest and fascination with the natural world and the inner workings of that world. To better understand that world might mean learning the patterns of animal migration so as to best time hunting efforts. It might mean watching the sun and the moon cycles to predict tides and thus insure bountiful fishing. It might even mean developing ways to cultivate and harvest plants that tolerate the environment in which we live. Learning about nature became one of the very first human sciences, probably even before humans knew anything at all about science.

In about 320 BCE a student of Aristotle and Plato, named Theophrastus, began an attempt to classify hundreds of different plants into specific types of growth forms (Silvius, 2007). Theophrastus was successful in classifying more than 500 plants using morphology into several major groups such as trees, shrubs, herbs, etc. (Silvius, 2007). He subsequently continued on in his work to publish his two most recognized books, Historia de Plantis (History of Plants or Inquiring into Plants) and De Causis Plantarums (The Causes of Plants) (Hughes, 1985). This extensive work developing the field of botany earned him the title "father of botany." Because of his early work examining the life of plants, their relationships to other plants, and how each plant seems to have a particular 'niche' in the environment, many also currently regard Theophrastus as the "founder of ecology" (Hughes, 1985). However, ecology as a formal science was not recognized until many years after Therophrastus' death.

Not until the Renaissance did a renewed interest of scientists in studying the relationships between creatures and their environments begin (Silvius, 2007). During this time many philosophers studied the earlier work of Aristotle including the "Great Chain of Being" which tied together nature and each organism's place in the "ladder of life" (Silvius, 2007). This line of thought continued with the creation of fields of study such as natural history which used a descriptive approach to understanding organisms in relation to their natural environment (Silvius, 2007). Developed in tandem with Natural History, the development of Natural Philosophy took a more quantitative approach to the natural world (Silvius, 2007). Natural Theology questioned the origin and purpose of the natural world, this opposed the current thinking of the day that nature and all of its organisms were part of a "machine," otherwise known as Mechanistic Philosophy (Silvius, 2007).

During the mid to late 18th century, Carl Linnaeus, a Swedish naturalist became an influential figure in areas of natural history and natural theology (Silvius, 2007). Linnaeus is probably best known as the "Father of Taxonomy" for creating the system of scientific classification, Linnaean Classification that scientists still use to this day (Waggoner, 2000).

Linnaeus spent much of his time classifying and labeling plants based primarily on flower and reproductive characteristics of the various plants he studied. Upon being granted nobility in his homeland of Sweden, he became known as Carl von Linne (Waggoner, 2000).

Aside from his best known accomplishment of the development of the binomial nomenclature system of scientific classification, Linne was also known for a number of other achievements. For example, Linne described in his book *Politia Naturae,* "On the Police of Nature" (1760) his ideas of how various populations are kept in check so that many organisms may all survive in one environment. In addition, Linne and his students conducted hundreds of experiments on the food preferences of grazing animals and this became the basis of some of his hypotheses about "ecological diversity" (Silvius, 2007). He suggested that each species had its own "station" or habitat and that this allowed for a variety of species to coexist in one area (Silvius, 2007). Many current ecologists credit Linne as one of the first scientists to draw connections between living things and their relationship to natural environment and therefore one of the very first to study "ecology".

In 1749, Linne also coined the term "*oeconomia naturae*" or "natural economy" to refer to the study of organs and how they contribute to the functioning of the whole (Silvius, 2007). This lead to the later development of the more formal study of "physiology". Although today's physiology studies tend to rely heavily on a reductionistic approach, Linne tended to incorporate both reductionism and holism in examining these systems.

Carl Linne was not the only biologist of this time who was interested in these questions about relationships in nature. Carl Ludwig Wildenow, a Prussian botanist, studied plant and animal relationships during about the same time as Carl Linne (Silvius, 2007). Wildenow was especially interested in the environment and in plant and animal communities over time (Silvius, 2007). According to Silvius, Wildenow began the subfield of ecology known as "ecological succession" through his studies (2007). Wildenow also proposed that similar climates tend to support similar types of plants and animals. This idea and the further development of the field of ecological succession have been greatly supported through current ecological research (Silvius, 2007).

Wildenow's studies became of particular interest to another young Prussian naturalist, Alexander von Humboldt. Humboldt is not only credited as a founding father of modern ecology, but he has also influenced a number of other biologists including Charles Lyell and Charles Darwin (Egerton, 1970; Silvius, 2007). Humboldt travelled extensively with partner botanist, Aime Bonplant, through Central and South America and through the Caribbean during the late 1700s (Egerton, 1970). Through his travels, Humboldt collected plant specimens and conducted extensive studies and field observations of the distribution of plant species. He observed and noted that various plant species might be grouped into "associations" and these associations can be predicted based on the characteristics of the environment (Silvius, 2007). Humboldt applied a descriptive and quantitative approach to his studies and because of this he is generally regarded as founder of the field of "biogeography" (Egerton, 1970; Silvius, 2007).

Humboldt is still widely credited as a major influence in the fields of science and philosophy of the 19th century (Egerton, 1970; Silvius, 2007). Humboldt's five volume series, *Kosmos*, is regarded as his attempt to show commonalities between the studies of science and philosophy (Silvius, 2007). His methods of inductive logic, drawing more general principles from the observation of a few specific examples, likened him to other great scientists such as Issac Newton and Charles Darwin. Darwin himself was very fond of Humbodlt's writing and in the year 1881, even remarked when asked about Humboldt's accomplishments, "I believe you are fully right in calling Humboldt the greatest scientific traveler who ever lived, I have lately read two or three volume (sic) again" (Egerton, 1970).

Naturalists who admired Humbodlt's work began laying down more foundational research into the field of biogeography. A Danish botanist, Johannes Eugenius Warming (known as Eugen Warming), greatly expanded on Humboldt's studies and included descriptive research on the effects of temperature, moisture and soil on plant communities and distribution patterns. Warming even attempted to classify plants by lifestyle and specific adaptations to their environment (Silvius, 2007). Incorporating abiotic factors into studies of plant and animal communities only helped to further advance the young field of 'ecology'.

Warming is widely credited with being the first scientist to use the term 'œcology' in a published work, which he used in the title of his book, *Œcology of Plants:an Introduction to the Study of Plant Communities* (Silvius, 2007). Although it was the first time that this term appears in the literature, it seems apparent that Warming's definition of this term aligns more closely with what we would currently call community ecology. Warming felt that only plant should be included when interactions among species, neglecting consideration of other species or non-living factors. It was not until 1893 that plant biologists voted to drop the 'o' from œcology and replace it with simply 'ecology' at the Botanical Congress conference in Madison, WI (Silvius, 2007). Although the term had circulated around the scientific community for a few years, it was not until this time in history that the term 'ecology' started to become more widely used and accepted.

Ironically, botanists and zoologists did not agree on the initial use of the term 'ecology'. Many zoologists felt that botany and zoology were separate fields entirely and, in particular, that botanists should not attempt to control both fields of study (Silvius, 2007). Likewise, botanists frequently viewed plants in isolation. Rarely were the implications of interactions between plants and animal herbivores or between plants and fungal parasites considered important to botanists (Silvius, 2007). Taxonomy took on a much bigger role at this time in biological history than the new area of ecology with its examination of whole systems based interactions.

Even Charles Darwin himself played a role in the further development of the formal field of ecology. Although Darwin never used the term ecology, many of the ideas proposed through his studies clearly showed ecological thinking. Darwin was influenced by the writing of Thomas Malthus who hypothesized about population growth patterns and resource limitation. From Malthus's writing Darwin further developed his ideas about the mechanism behind evolution, 'natural selection' (Raven, et al. 2010). Natural selection was intrinsically ecological because it emphasized the role of competition between and within species, integrated abiotic factors as influential to adaptations, and accounted for large scale changes in populations or organisms.

Animal biologists instead considered adopting the term 'ethology' instead of 'ecology' to be used when referring to studies of animal behavior (Silvius, 2007). Again this view was considered somewhat in isolation of other surrounding factors. Interactions between plants and animals (i.e. herbivore/plant coevolution), or interactions between animals and abiotic factors were not given much attention. Additionally, the rise of ethology coincided with a growing number of experiments from animal behaviorist, Konrad Lorenz (Lorenz, 1973; Silvius, 2007). Lorenz's discovery of animal imprinting with Greylag geese later led to his winning the Nobel Prize in 1973 along with Karl von Frisch and Nikolaas Tinbergen (Lorenz, 1973).

In 1902 *Science* published an interestingly vehement article written by William Wheeler discussing the vices of zoologists using the term 'ecology'. Wheeler not only decries the use of the term by anyone except the botanists but he degraded the burgeoning field as completely unnecessary (Wheeler, 1902). Wheeler stated,

> A study of recent literature reveals the fact that zoologists are much in need of a satisfactory technical term for animal behavior and the related subjects which go to make up what is variously known as 'natural history', 'œcology', and 'biology' in the restricted German sense. The need is also apparent in recent discussions in *Science*. As the number of workers in the field above indicated is rapidly increasing, any attempt to fix the terminology, if at all feasible, is certainly timely. In the opinion of the writer all the terms above mentioned are open to serious objection and should be avoided at least by zoologists who use the English language. (Wheeler, 1902, p. 971)

Wheeler further implied that zoologists should not adopt any term created and used primarily by botanists because the work they do is intrinsically different (Wheeler, 1902). He suggested that the study of animals is far more complex than the study of plants and that only botanist need to be concerned with the abiotic effects of the environment on their subjects. Zoologists, according to Wheeler, work with various parts of animal systems and require greater knowledge and understanding of the complexity of animal systems (1902). Wheeler (1902) stated:

> And this leads us to a further reason for abandoning the term 'cecology' in zoology, and for suggesting the adoption of one essentially different. While botanists and zoologists alike are deeply interested in the same fundamental problem of adaptivity (sic), they differ considerably in their attitude, owing to a difference in the scope of their respective subjects. The botanist is interested in the effects of the living and inorganic environment on organisms which are relatively simple in their responses. The zoologist, however, is more interested in the expressions of a centralized principle represented by the activity of the nervous system or some more general and obscure 'archoeus' which regulates growth, regeneration and adaptation, carrying the type onward to a harmonious development of its parts and functions, often in apparent opposition to or violation of the environmental conditions. (p. 974)

Wheeler offered an interesting glimpse into some of the fierce debate that was waging between and among the zoologists and the botanists. Even today many times various specializations with scientific fields work in striking isolation from each other. Ecology became more of an attempt to mesh some of these ideas and examine emergent properties by taking a systems-based view of natural phenomena. Ecology started to grow as a respected field due to the work of many biologists who promoted the idea that animal systems can be affected by plants and abiotic forces and vice versa.

During this time in scientific history of obvious conflict between the botanists and the zoologists, an unlikely partnership developed. American plant ecologist, Frederick Clements, was interested in the writings of Humboldt about plant associations (Silvius, 2007). Clements went on to suggest the concept of 'biotic communities', giving equal weight to plants and animals within a habitat (Silvius, 2007). Clements' work emphasized interrelationships among plants, animals and abiotic factors in which they live (Silvius, 2007).

Another scientist and colleague of Clements, Victor Shelford, worked as a zoologist at the University of Illinois from 1914 to 1946 (Silvius, 2007). Shelford's expertise lay in studying the responses of animal populations to changes in their environment. Through this work, Shelford developed his Law of Tolerance. Shelford's Laws of Tolerance suggests that all animals have specific environmental ranges in which each functions optimally. Tolerance ranges are species specific and will vary depending on the habitat and lifestyle of each organism (Silvius, 2007).

Eschewing the traditional thinking of the time that botanists and zoologists could not possibly work together as researchers, Clements and Shelford joined research forces (Silvius, 2007). Many scientists at the time, such as was noted in the article by Wheeler, felt that nothing particularly noteworthy could come of such a union between these two seemingly diverse fields. In actuality, the Clements and Shelford merger represented the growing need to recognize how intrinsically linked all fields of science, and even mathematics, are together.

Together this duo published the book, *Bio-ecology* (1939), where they introduced the idea of 'ecological biomes', specific geographic areas defined by annual temperature, precipitation and dominant plants and animals (Molles, 2010). The biome concept is still used currently in ecological studies as can be appreciated when reviewing any number of popular ecology textbooks (Molles, 2010). The notion that habitats could be identified and classified as entire units instead of individual organisms represented a huge step forward in further breaking down barriers between the two fields of zoology and botany and also between the fields of biogeography and physiology. This more holistic view of natural systems seemed to get a boost from this pair of scientists, still there were many who pressed for more rigidity and isolationism regarding each field of study (Silvius, 2007).

According to Silvius, perhaps Clements biggest challenger came in the form of Henry Gleason in 1926 (2007). At this time, Gleason published "The Individualistic Concept of the Plant Association," in which he dismissed claims by Clements that plant communities can act as 'superorganisms'. Gleason asserted that each plant community arose through an independent, random, and unpredictable set of processes (Silvius, 2007), harkening back to Leonardo da Vinci's extensive work introducing and supporting reductionism as a philosophical viewpoint and as an epistemology in itself. Gleason's full commitment to an individualistic view of communities lead him to reject a notion of emergent properties and instead, he supported the idea that communities can be understood by studying their parts since the sum of the parts is still equal to the whole (Silvius, 2007).

Even with some of the resistance to the developing field of ecology, there were other scientists who supported the work of scientists such as Clements and Shelford. A prominent English botanist by the name of Arthur Tansley developed the term "ecosystem" to describe the combination of organisms, including the various species, and the physical environment in which they reside (Molles, 2010; Silvius, 2007). Tansley was one of the first scientists to suggest that an ecosystem can function, develop and grow as a holistic unit, and he also supported the idea that ecosystems cannot be studied effectively by simply examining their parts in isolation (Silvius, 2007). Tansley promoted the ecosystem as a whole unit and moved its classification to a higher hierarchical level (Silvius, 2007). Many ecologists attribute the success of the field of study of "ecological succession" almost entirely to Arthur Tansley.

Some other noteworthy scientists who also helped support and advance the field of ecology at this time include August Thienemann who introduced the concept of "nutrient cycling" and coined the terms *producers, consumers, decomposers*. R. A. Lindeman also contributed to advancing this field by developing the field of "ecosystem ecology" through studying the trophic (feeding) levels. Additionally, Eugene and Howard Odum developed the field of "systems ecology" using computer analysis to understand ecological systems. Lastly, Edgar Transeau developed research into the ideas of energy budgets and primary production by ecosystems. These noted scientists of this time in history helped to further develop and advance the field of study that is ecology and better defined more specific niches of study with such a broad field (Silvius, 2007).

The 20th century saw a dramatic rise of the environmental movement that has continued to shape the study of biology and ecology. Aldo Leopold is frequently regarded as one of the instigators of the modern environmental movement (Silvius, 2007). Many scientists feel that his writings were deeply moving and a powerful way of conveying the trials and tribulations of undertaking an ecological restoration project. Leopold himself worked in Iowa and Wisconsin in various aspects of wildlife management (Aldo Leopold Foundation, 2012). He wrote and published a number of professional and personal articles and eventually went on to publish a textbook in the area of wildlife management (Aldo Leopold Foundation, 2012). Leopold showed an incredible likability through his writing and encouraged the development of human experience through exploration and interaction with the natural world (Aldo Leopold Foundation, 2012).

In 1949, the now iconic book, *A Sand County Almanac* was published (Aldo Leopold Foundation, 2012). This book was a compilation of writings and essays of Aldo Leopold and was published a year after Leopold suffered a heart attack and died (Aldo Leopold Foundation, 2012). This book has sold over two million copies and is still used in ecology classrooms and is highly regarded by ecologists today (Aldo Leopold Foundation, 2012). Many would consider this work to be timeless in the greater picture of science writing. As was so aptly stated by the Aldo Leopold Foundation (2012) about the *Sand County Almanac*,

> With over two million copies sold, it is one of the most respected books about the environment ever published, and Leopold has come to be regarded by many as the most influential conservation thinker of the twentieth century. Leopold's legacy continues to inform and inspire us to see the natural world "as a community to which we belong" (Aldo Leopold Foundation, 2012).

The publication of this collection of essays helped fuel the environmental movement.

Another influential biologist, Rachel Carson, went on to write the book *Silent Spring* (1962) which had a strongly galvanizing affect on the environmental movement (Lear, 1998). Many would say that her book did not actually start the environmental movement but that it did serve to ignite furor over the state of the environment and fuel the unification of the movement. Carson had written several articles prior to her book for the purpose of educating people about the beauty and wonder of the natural world (Lear, 1998). *Silent Spring* was a response to her growing concern and disgust over industries' blatant use of chemicals without regard for their environmental effects. Through her book, Carson warned the public of the potential detrimental effects of long term, unregulated pesticide use. Carson urged people to view the natural world in a new light, as part of it instead of masters over it (Carson, 1962).

Carson and Leopold were largely responsible for making "ecology" a household word (Silvius, 2007). The environmental movement started to take shape in the 1960's and was further ignited by the writings of Carson and Leopold (Silvius, 2007). The United States has seen the continuation and further growth of the environmental movement and ecological awareness because of the work of these two authors and those others previously discussed.

Current State of Environmental Literacy in the United States

Kevin Coyle's report, *Environmental Literacy in America* (2005), succinctly categorizes environmental knowledge into three levels of understanding. The first level of understanding is "Environmental Awareness" (2005). Coyle posits that at this level a person has simple knowledge that a particular environmental problem exists. At this level there is generally no deeper understanding of the complexity of the environmental issue or what causes it. Most people in the U.S. function at this level of understanding. For example, most people you approach could say yes they have heard of climate change, but when asked what causes it, most would be unable to answer (Coyle, 2005).

The next level of environmental understanding is "Personal Conduct Knowledge" (Coyle, 2005). Someone at this level not only is familiar with a number of environmental problems and issues, but also knows some of the things that cause them. Their knowledge also guides some of their actions. These people are 5%-50% more likely to engage in environmentally responsible practices, such as turning off the faucet when brushing their teeth or using low energy light bulbs in the home (Coyle, 2005, p. xiii). People at this level of understanding do not have a complex, working knowledge of environmental problems. Generally, cause and effect problems are well understood, but anything that involves more than one step has yet to be acquired. For example, knowing why you would not want to put batteries in the trash involves more than one step to understand. Learning that when batteries go to the landfill they will leach battery acid into the ground, that will seep into ground water and can contaminate fish in a nearby stream, demonstrates a complex system and is more than most at this level will know (Coyl,e 2005).

According to Coyle, the highest level of environmental knowledge is the level of "environmental literacy" (2005). At this level a person understands the complexity of environmental systems and how our actions can affect those systems. Environmentally literate people know what the problems are and what needs to be done to address them. An environmentally literate person also affects change through personal action. These individuals do what they can to improve and conserve the state of the planet and its resources. This group accounts for the smallest percent of Americans. It is estimated that only 1%-2% of Americans function at this level of environmental knowledge (Coyle, 2005, p. xiii).

Coyle further stipulates that overall, the key feature to bringing about greater environmentally conscientious action is instilling a sense of ownership (2005). The best way to bring about a sense of ownership is by placing people in direct contact with their environment, according to Coyle (2005). This can be supported through activities in schools such as place-based learning, school-yard gardens, outdoor classrooms, field trips, etc. These types of active learning opportunities cannot be viewed as simple enrichment, but rather as a critical addition to the curriculum (Coyle, 2005).

State of environmental literacy in the U.S.

One statement that could be used to appropriately summarize the state of environmental knowledge in the U.S. is: "Americans believe they know more than they do and still less than they should" (Coyle, 2005, p. iv). When random adults were surveyed using the NEETF/Roper environmental knowledge survey (see Appendix C), only 32% of people who completed the survey earned a passing score (Coyle, 2005, p. 3). Only about 1-2% got all or almost all of the questions correct on this survey (Coyle, 2005, p. 3). Likewise, when given a test of energy literacy only 12% of those surveyed earned a passing score (Coyle, 2005, p. ix). Knowledge about energy usage appears to be worse than general environmental knowledge. This low level of environmental knowledge also holds true for “influentials” or those people that the Coyle report (2005) identifies as in positions of leadership or decision-making.

One interesting feature that came to light through Coyle's survey was a large disparity between the environmental knowledge of men and that of women. According to Coyle, women consistently scored lower in every question of the survey and also on the energy survey and men seem to have a greater knowledge base when it comes to environmental issues than women (Coyle, 2005). This may be in part because of the types of interests and jobs men tend to hold may involve more technology and energy needs, requiring them to learn more about the environment. On the other hand, women seem more optimistic about our ability to improve environmental problems and were more willing to take personal action to help achieve that (Coyle, 2005).

Interestingly, those who graduated high school after 1990 did not fare any better than those who graduated before that (Coyle, 2005). In general, typical U.S. schools are not producing environmentally literate students. In fact, adults do not generally acquire their environmental knowledge from personal experience, nor from school. Overwhelmingly adults and children get their environmental information through the media (Coyle, 2005).

The media can be an effective means of conveying environmental information, but unfortunately like most scientific and complex information the media tend to simplify and over generalize (Coyle, 2005). In order to produce truly environmentally literate adults, people need to understand complex systems; this cannot generally be achieved through media as it functions currently. Additionally, the best way to produce adults who not only understand these environmental issues but who also act on them is to give them direct experience with the environment (Coyle, 2005). This is where formal and informal science education can play a role in helping develop a greater interest and better understanding in environmental problems.

A growing issue in the U.S. is “Nature-Deficit Disorder” developing in children. The Coyle report states that a typical seven year old today can easily recognize an average of 200 product logos but cannot name a single tree near their home (Coyle, 2005, p. 97). Children are spending an increasing numbers of hours indoors for a variety of reasons. Growing interest in technology, computers, television, and cell phones may be some of the factors keeping children inside. Over-scheduling by well-meaning parents, programmed afterschool sports and activities tend to take time away from exploring the outdoors. Also, safety concerns are increasing currently more than they were in the past. Many parents feel it necessary, especially in urban environments, to keep children inside in order to keep children safe (Coyle, 2005).

In light of this growing issue, an enormous 95% of those surveyed supported the idea of including environmental education in schools (Coyle, 2005, p. xvii). Organizations such as No Child Left Inside (NCLI) feel that it should not only be included but that it should be greatly upgraded to be considered part of the core curriculum (No Child Left Inside, 2007).

Surprisingly, most people recognize the growing nature deficit and feel that it is an important enough topic that children should learn about it in school. In line with this, Coyle's book (2005) states that environmental education is the key to greater environmental literacy.

No Child Left Inside Act

The NCLI Act was first submitted to the House of Representatives on April 22, 2009 (Earth Day) by Representative John Sarbanes of Maryland and Senator Jack Reed of Rhode Island, as a way to improve and better incorporate environmental education since the signing of the NCLB. NCLI was developed to fill a void that was created in schools in regards to environmental education and to counter the effects of the growing nature-deficit issue. The purpose of NCLI was to greatly improve and expand environmental education in U.S. schools. The goals of NCLI include:

- Expand the knowledge base of environmental education. This includes support for research, curriculum and methodology development.
- Supporting states to create State Environmental Literacy Plans. This would prompt state governments to think about the impact of environmental education and what work still needs to be done in this area.
- Training for environmental education professionals. This would include training teachers and other formal and informal educators. Enlisting professionals at zoo, museums, aquaria, and parks to participate in informing the public about environmental needs and issues.
- Enlisting the help of other professionals such as doctors, nurses, business people, media, and weathercasters. Make training available in order to reach a wide audience, not just school children.
- Organizing environmental education so that it can follow a logical pattern just like other core subjects. Using other educational opportunities such as outdoor classrooms, afterschool programming, classroom gardens, and field trips can help advance this curriculum. These tools should be seen as a direct means of fostering a vital sense of ownership in students and not just viewed as optional exercises.
- Integrating environmental education across subjects. There are whole complex systems affected by environmental problems. For instance, a fishing business is greatly affected when the lake's water chemistry changes due to acid rain. This is a good example that incorporates three different subjects, business, chemistry, and biology, into one example. Collaboration could be

> the key to fostering some meaningful changes in curriculum using environmental education as fuel (No Child Left Inside Foundation, 2007).

The NCLB act was signed into legislation under the George W. Bush administration. The NCLI act came about due to the narrowness of the original NCLB act. The current NCLB act focuses so heavily on standardized testing and traditional forms of assessment that many environmental programs and activities have been sidelined in favor of more test-focused curriculum. NCLB threatens to increase the rate of nature-deficit disorder in children and produce adults that are not only uninformed about the complexity of environmental problems but incapable to making choices that might help reduce some of these problems. NCLI has made some positive strides in congress during 2012. In April 2012 Environmental Protection Agency (EPA) administrator Lisa Jackson announced the development of the Federal Interagency Task Force on Environmental Education (No Child Left Inside Foundation, 2007). Jackson also announced a further commitment of $5 million in EPA funding to be dedicated towards environmental education (No Child Left Inside Foundation, 2007). These actions should increase interest and action on the part of government officials in advancing environmental education in the U.S.

The future success of NCLI Foundation will help insure that environmental education will be better incorporated and supported in school curriculum. One of the primary goals of NCLI would be to raise the public's level of environmental knowledge from simple environmental awareness to personal conduct knowledge. By increasing the public's knowledge by just one level such as this it is estimated that the U.S. could save more than 75 billion dollars in energy costs (Coyle, 2005, p. 55). For this goal to be actualized, environmental education is the key. The main goals of environmental education are as follows:

- Students should have awareness of the environmental issues and understand what the problems are that need to be addressed.
- Students should understand how those problems can be best addressed. They know what needs to be done to help improve the problems.
- Students should have the ability to make good decisions when faced with choices that may affect the environment. This is a big part of moving from the level of simple environmental awareness to personal conduct knowledge.
- Students should have attitudes that bear the environment in mind (Coyle, 2005, p. 53).

These goals should not just be limited to students; these are excellent goals for everyone. By employing some of the strategies, such as using media and informal educators, a greater degree of environmental knowledge in adults as well as children could be achieved. It is likely that as environmental problems increase and as public understanding of these issues decreases there may be an increasing demand for environmental education for everyone (No Child Left Inside Foundation, 2007).

Finally, in addition to increasing students' level of environmental knowledge, instating NCLI might also have other beneficial effects on students. Preliminary data suggests that students who take courses on environmental education or participate in an environmental related program show improvements in other areas also (Coyle, 2005). These students tend to show improvements in standardized test scores in math, English, writing, science, and critical thinking skills. Students also seem to get a boost in problem solving and in personal conduct integrity. Working together with peers to help solve an environmental problem fosters collaboration, cooperation and problem solving (Coyle, 2005).

Environmental studies programs also show another surprising effect. These programs tend to have an equalizing effect on populations from different socioeconomic backgrounds or cultures. Additionally, since environmental issues are usually also social justice issues, students in urban or in environmentally degraded living conditions may be even more drawn to help improve their own health and the safety of their neighborhoods. More research is needed to support the validity of these suggested findings (Coyle, 2005).

Overall, support of environmental education and the NCLI act is likely to produce multiple positive effects on children and adults. In light of all the growing environmental problems, finding ways to best support environmental literacy seems imperative. Encouraging hands-on activities to promote a sense of ownership is one of the best ways to achieve even the shift from personal conduct knowledge to the greater goal of true environmental literacy. Environmental literacy does not happen in a "microwave," it takes time and training to achieve (Coyle, 2005).

State of Science Education in Higher Education in the United States

Two recent reports, *Beyond BIO 101* (Jarmul et al., 1996) and *BIO 2010* (National Research Council, 2003), were written to provide a critical look at science education in college classrooms. These documents showcase a variety of issues from increasing class sizes, under prepared students, and faculty with less class preparation time. Examining these documents focuses attention onto these problems and develops history around the current state of science education at the college level.

Beyond BIO 101

The report, *Beyond BIO 101* (Jarmul et al., 1996) was created as a compilation of the efforts of more than 200 colleges and universities across the country when asked to rethink structure, curriculum and the implementation of biology inside and outside their classrooms. This document highlights a number of innovative and successful transitions from traditional biology programs to more forward-thinking programs, demonstrating that positive changes can occur even in the sciences. Many of these examples can serve as models for other schools with the changing science landscape in mind.

Beyond Bio 101 begins with a description of some of the current issues facing college biology departments (Jarmul et al., 1996). Most departments are faced with increasing numbers of students entering biology, thus larger classes, and a gradually decreasing number of faculty in the sciences. Generally, larger classes with fewer faculty and those faculty having increased time demands placed on them, are becoming more the norm (Jarmul et al., 1996).

Some colleges have developed creative ways of dealing with the increasing number of students and the burden placed on faculty to deliver personalized education to all of them (Jarmul et al., 1996). Use of technology is growing as one of the most common ways to try and reach all students, even those in very large classes. Jarmul et al. suggest that utilizing web-based discussion boards, wikis, and other online programs can help bridge some of these gaps (1996). Additionally, some students who may not interact in a large classroom may willingly participate in an online discussion. Development of these alternate teaching tools requires time and effort on the part of faculty. Administrators should be supportive of these efforts and afford faculty the time and compensation required for continual course development and modification (Jarmul et al., 1996).

Based on the recommendations of Jarmul et al. (1996), more and more students are viewing biology as the key to a good career, which means more students are entering college as biology majors. Due to these increases, departments are being forced to address the reality of more and more underprepared students entering their classrooms, and a number of colleges in the local South Louisiana area have developed creative strategies to insure that these students do not get left behind. For example, Xavier University in New Orleans uses an intensive summer study program that combines classroom practice and preparation with exposure to research starting with children as young as 7th grade (Jarmul et al., 1996). They continue this program until they reach college age, at which time most will matriculate to Xavier University well prepared to engage in college level work. This program has proven to be extremely effective and Xavier can boast the highest number of Black students admitted to medical school out of all the colleges in the U.S. (Jarmul et al., 1996).

Even in light of increasing numbers of students entering the biological sciences, still the number of students being admitted to medical school and graduate school appears to be decreasing (Jarmul et al., 1996). Jarmul et al. (1996) claim this too presents a new challenge to colleges to expose students to a variety of experiences and options. Several of the schools included in this report demonstrated their commitment to engaging undergraduates with research (Jarmul et al., 1996). The benefits of this type of collaboration between faculty and students are immeasurable. Research can expose students to a variety of options they may not have considered before and build relationships with role model faculty who could provide critical support and networking for students (Jarmul et al., 1996).

BIO 2010

In another report, *BIO 2010*, the focus was to assess the needs within current college biology programs (National Research Council, 2003). The secondary focus of this report was to better understand ways to encourage and prepare students for the fast developing area of biomedical research. With biology growing as a field of study for college students and the increasing demand for more research in biomedical areas, this report provides a much needed evaluation of the current state of biology teaching. This report also provides recommendations for the future of biology education in college classrooms (National Research Council, 2003).

The committee that compiled this report states that undergraduate education is the key to developing future researchers (National Research Council, 2003). Based on current estimates, careers in biomedical research are expected to grow in the future (National Research Council, 2003). This will create job opportunities that many students may not have considered. In order to better prepare and encourage students for potential careers in biology or biomedical research the committee shared these recommendations (National Research Council, 2003):

- Stronger training of biologists in the physical sciences and mathematics. Students should be able to see the linkages between these fields with biology. This report even suggests a completely revised curriculum that would integrate math and physical science into every science class. There was also the addition of some required engineering courses, such as biological design, that all biology majors would need to take. Again this would expose students to even more options than they may have considered before.
- Take a more interdisciplinary approach to biology programs. More communication between departments can facilitate the inclusion of more diverse subjects into a student's schedule of courses. Creating a general science course that may use faculty from multiple departments could give students a more balanced understanding of biological phenomena.
- Developing more engaged learning techniques for biology students. Investigative labs, active learning, experiential learning, student-driven experiments are all ways to make learning not only more interesting but memorable and long-lasting. These types of classes have the power to "turn on" a student to science and encourage them to pursue science as a career.
- Faculty development needs to be supported and encouraged by administration. This is a feature that cannot be ignored. If faculty does not have the time or financial support to participate in development or to attempt curriculum changes, then it will never happen. Faculty is the key to getting changes in how and what we teach. They are frequently an integral link between where a student currently is and where they want to be.
- Reassessment of standardized testing. The committee determined that standardized testing frequently hinders forward progress in the classroom. Just as NCLB has shackled many teachers into "teaching the test", MCAT, GRE and the like, have greatly restricted much of the flexibility college professors have in changing programs and curriculum.
- Exposure to research should be encouraged for all undergraduates. The experience of participating in research in itself is a learning experience. It should be valued as such and not trivialized as just extra credit (National Research Council, 2003, p. 8).

Science research in education

The report, *Science Research in Education*, published by the National Research Council, focuses on how scientific practices can be best incorporated into educational research

(Shavelson, 2002). The National Research Council (NRC) compiled a number of factors to bear in mind when conducting educational research. The NRC suggests using specific standards when conducting scientific research especially in regards to educational research. One of the NRC recommendations is to ask empirically based questions. Questions developed within a scientific paradigm should be able to be addressed using formal testing methods. Research questions should also be linked to appropriate theory and all of your questions should be grounded in theory (Shavelson, 2002).

When deciding on research methodology, those methods chosen should directly address questions. Methods should match questions such as qualitative, quantitative, or mixed methods. Results need links to well founded explanations. Results should be understandable and make sense to other researchers. Likewise, the results of independent research projects and studies need to be available for retesting by others. Allowing other researchers to test the results of a study only strengthens a study's conclusions. Lastly, researchers should allow for dissemination and critique of their work. Critique can help shape and modify research so that one can best develop future questions and strengthen current research.

Shavelson claims that educational research is also highly context dependent (2002). Combining research methods may help better illuminate the context in which your research is situated. Also, educational research must always link to practice. Practice should drive the questions and research should always link back to what is actually happening in the classroom. To do this makes the research more powerful and keeps the results meaningful.

Common themes

In the reports *Beyond Bio 101* and *BIO 2010* both place strong emphasis on undergraduate research. The authors of both reports suggest undergraduate research as an avenue to encouraging students in the sciences, giving undergrads a unique learning experience, and establishing a personal connection to faculty that is vital to retaining some students. Some schools have been remarkably successful at achieving this goal such as New York City College where half of all their graduates have participated in some form of research (Jarmul, 1996).

In both of these first two reports, Jarmul (1996) and the National Research Council, (2003) also strongly support engaged teaching styles. In the past few decades biology research has changed dramatically, but our style of teaching has changed very little (Jarmul, 1996; National Research Council, 2003). Many suggest that if we are to teach up to date science, then our methods of teaching should also be up to date. Many college classrooms are still steeped in the old "preacher on the pulpit" method of lecture. With the growing number of smart phones, IPads, and other similar technology, students come into our classrooms with the ability to access any information that we hand to them on their own. Why not do more than just "give" out information? Many would agree that we must engage our students more than we do (Jarmul, 1996; National Research Council, 2003). According to Jarmul (1996) and the National Research Council, (2003) using technology, investigative labs, active teaching and student-driven activities are some of the teaching methods that can make lessons real for students.

In light of all of these proposed changes to curriculum the authors of these reports also agree that faculty training is key (Jarmul, 1996; National Research Council, 2003; Shavelson, 2002). Administrations should support faculty development and understand that effectively changing curriculum takes time and effort (Jarmul, 1996; National Research Council, 2003). Shavelson recommends that the last report on scientific research in education would also support the time it takes for faculty to construct valid studies of education-based questions (2002). Even educational research should be grounded in scientific methodology (Shavelson, 2002). Faculty should have the financial support and time allowances to conduct and take part in this type of research (Jarmul, 1996; National Research Council, 2003; Shavelson, 2002).

How these ideas relate to my own thinking and teaching

When attending the Ecology and Education Summit on Environmental Literacy for a Sustainable World in Washington, D.C. in 2010, there were several ideas that emerged as central points of focus. One of the main emerging themes of the meeting, though, was that there was not yet consensus on what constitutes an environmentally literate person, nor how we go about helping someone become environmentally literate. There was a great deal of discussion about these topics at the summit and it became clear that not many people had been talking about it before. It seemed as though this was an area of science education that was begging to be explored.

One strong sentiment was the development of science curriculum that is more focused on systems-based thinking. I personally love this idea and hope to model my own teaching around a systems-based approach. Some classes lend themselves to the idea that everything is part of another system, such as ecology which is all about relationships. Other classes too could better incorporate a systems-based approach. Just as was mentioned in the *BIO 2010* report, interdisciplinary thinking is likely the key here. Tying together seemingly disparate subjects and showing how they all build on one another would help develop this goal.

Another recurring theme from the summit was the integration for more active learning techniques and exposing students to the outdoors. Getting students outside for experiences such as field-based laboratories or outdoor classrooms will not only encourage investigation with the outdoors but could engender a greater appreciation for the environment. These types of experiences have a two-fold effect, they tend to increase a student's sense of ownership and likewise help develop greater environmental literacy, and they can encourage meaningful learning and create deeper, more memorable learning experiences.

Lastly, all of these sources seem to agree that teachers need to better incorporate technology into our teaching and encourage student participation of research. These two features can also be combined to create things like simulation software to mimic natural ecosystems. This could improve understanding of ecological systems and problem solving while incorporating new technology. Involving students in research also gives them a new perspective for how science is done and hands-on experience in areas they may not have encountered before. Many excellent ideas were presented in these reports and at the summit, it may take some time, but I feel that these types of practices will become more common in the near future.

How Deep Ecology and Systems-Based Thinking can Influence Ecological Literacy

Systems thinking did not come about until the early to mid 1900s. The history of the deep ecology movement stems from several other fields including chemistry, physics and biology. Systems thinking promoted the ideas that the essential properties of a living system only exist within the whole and emergent properties appear at different levels. This came as a direct rejection of the reductionist or analytical method of the Cartesian paradigm. By observing and studying the whole one can learn more than simply studying the individual parts. This period represents the basic foundation of central themes found in deep ecology (Capra, 1996). Figure 6 is a graphic that I created to depict a brief genealogy of some of the founders of the deep ecology movement. The tree image in this figure represents the founders as roots of the development and newer scientists as branches of that tree. Together both show growth of the movement and development into a more respected science. A more detailed account of the history behind the deep ecology movement and development of systems based thinking systems follows below Figure 6.

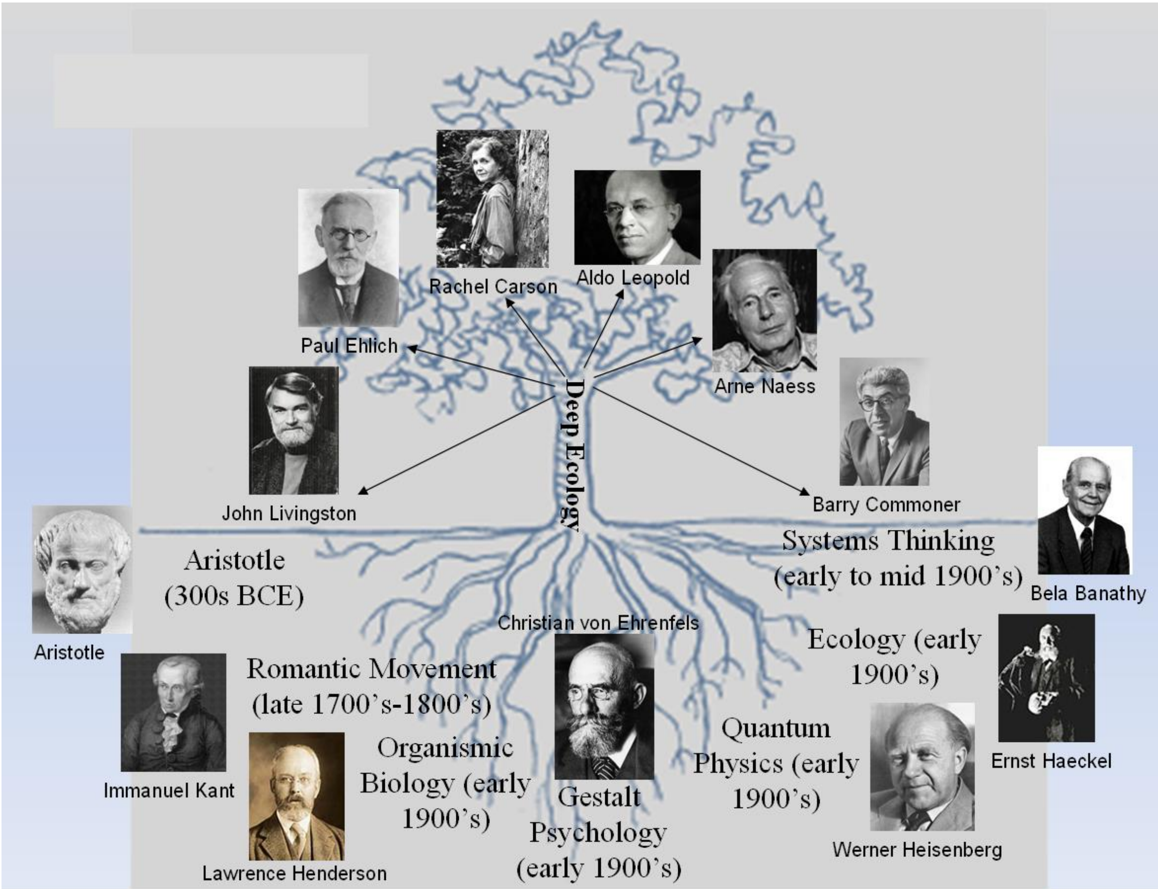

Figure 6. A brief display of the growth and development of the deep ecology movement.

Ecology as described by Fritjov Capra

During the 300s BCE, Aristotle distinguished between substance (matter) and form (processes), but also linked them through the concept of development when studying living things. He believed that matter could only be separated from form through abstraction and described the idea of entelechy or self-completion which could eventually lead to self-realization (Capra, 1996). These ideas helped form some of the early bases for ecological understanding of the universe. Aristotle helped influence the foundation for the idea that the structure, pattern, and processes of life are inseparable.

According to Capra, artesian mechanism developed as a method of analytical thinking (1996). This method strongly encouraged the breaking down of complex phenomenon into smaller questions. Through this method a person could learn about the whole through a sum of the parts. The scientific revolution was propelled by several scientists including Descartes, Copernicus, Galileo, Bacon, and Newton who restricted the studying of phenomenon to that which was directly quantifiable (Capra, 1996). Capra claimed this revolutionized how the world viewed science and that which qualified as science (1996).

To Descartes, the world was a whole machine, including all of its living parts, which could be better understood by breaking it down into parts. This inspired other epistemological methods such as reductionism and atomism. Descartes viewed the world as a perfect machine that could be best understood and broken down through mathematics and scientific reasoning (Capra, 1996). This new view promoted by Descartes was a movement away from the previous thinking of philosophers such as Aristotle. Aristotle attempted to draw distinctions between substance and form and connected them both through development. The development provided links and foundations for the further understanding of matter as substance and form as process. Aristotle also believed in the inseparability of matter and form. The two were intrinsically connected and could only be viewed as separate through abstraction. Aristotle actually provided an early foundation to the future development of philosophies on holism and ecology. He promoted the idea that structure, pattern and the process of life are inseparable (Capra, 1996).

In the late 1700s-1800's the Romantic Movement grew, which brought forth new ideas from philosophers such as Kant (Capra, 1996). Kant was an idealist who tried to better understand organic form. He separated the phenomenal world from the world of “things-in-themselves” (Kant, 1987). Kant looked at science as a means of explanation that was by itself insufficient to capture the whole picture of living things. He felt that science's explanation of natural phenomenon needed to be supplemented with some explanation of its purpose. Kant argued that living things were not machines but instead self-reproducing, self-organizing wholes. Kant also promoted the idea of 'self-organization' as a means of defining the nature of living things (Kant, 1987). Additionally, this period showed the first strong opposition to the mechanistic Cartesian paradigm. A return to the Aristotelian tradition of conceptualizing biological form as linked to a dynamic pattern of relationships started to develop during this time in history. More scientists began to view nature as an integrated, harmonious whole and Earth as a living being.

During this time, Johann Wolfgang von Goethe was the first to use the term 'morphology' for the study of the biological form, which implies dynamic development (Goethe 1817). Goethe also demonstrates a ‘form’ in nature is a pattern of relationships within an organized whole. Likewise, Kant believed that science could only offer mechanistic explanations. He argued that organisms are self-organizing and self-producing, which sets them apart from machines (Kant, 1790). Both of these philosophers and many others during this time period offered additional support for a connection between matter, form, and process.

The 19th century saw the rise of scientists such as Virchow and Pasteur who brought the focus back to a more reductionist view (Virchow, 1859). The discovery of 'germs' initiated the field of cell biology, along with the advent of the microscope (Capra, 1996). Again the reductionist and mechanistic view comes back into popularity. Although an enormous advance in its own right, this view also advanced the misconception that bacteria are the only things that cause disease.

Capra maintains that vitalism arose as a backlash against reductionist biology as was found in biology and chemistry (1996). Vitalism asserts that reduction down to parts is insufficient to fully understand the nature of life. Furthermore, the behavior found in living things is part of an integrated whole that cannot be separated and should not be studied as parts alone. Vitalism introduced the idea of self-organization again emphasized patterns and relationships. Vitalism was seen in sharp contrast to the mechanistic movement. Developmental biology showed that living things do behave differently than machines. When development is interrupted or cells removed from a developing egg mass, the living thing must alter course in order to complete development into a whole organism (Capra, 1996). Hans Driesch (1908) attested that machines were incapable of this type of developmental flexibility.

Organismic biology developed as a new option opposing views of life from the vitalism or mechanistic perspectives (Capra, 1996). The new field of organismic biology served as the foundation of the later development of systems thinking. Through organismic biology we see a shift from viewing living things for their function to their organization. Here scientists started to look at organisms in terms of relationships and how parts all perform together. This fundamental turn in the way science approached the world was key in helping to fuel future development of a true ecological philosophy. In 1929, one of the catalysts of the organismic biology movement was Joseph Woodger who described organisms in terms of their organizing relations (Capra, 1996). This idea emphasizes the entire system of a living thing and how behavior may even be affected by workings of the organism (Capra, 1996).

In 1917, Lawrence Henderson coined the term 'system' to refer to living organisms (1917). This time was largely seen as a beginning of systems thinking with focus on organization in order to comprehend life processes. Development of the field of quantum physics during this period also helped to further suggest that the “fundamental building blocks” of matter may not exist.

Modern ecology comes about as an offshoot of organismic biology. Ecology shows that the focus is on the relationships that link all living organisms on Earth and living with non-living. Some scientists speculated that communities of living organisms might also be considered 'superorganisms' connected by a network of interactions. Noteworthy ecologist, Ernst Haeckel coined the terms ecology and phylum further implying interconnectedness between all living things. Haeckel revealed this term and first discussed it in 1869 at a presentation of philosophers at the University of Jena (Esbjörn-Hargens & Zimmerman 2009). Haeckel stated,

> By ecology we mean the body of knowledge concerning the economy of nature- the investigation of the total relations of the animal both to its inorganic and its organic environment; including, above all, its friendly and inimical relations with those animals and plants with which it come directly or indirectly into contact - in a word, ecology is the study of all those complex interrelations referred to by Darwin as the conditions of the struggle of existence (Esbjörn-Hargens & Zimmerman 2009, p.159).

This was a time when we see true foray into the basics of system thinking. Here we are introduced to the concepts of community and networks for all system levels and begin including living with non-living into the bigger picture of the biosphere (Capra, 1996).

Moving beyond organismic thinking, systems thinking developed as a way of holistically viewing living things. Systems thinking encourages looking at life by means of whole systems (Capra, 1996). Only by studying the whole system can the true nature of the organism come out. When the organism is dissected down into its parts then the emergent properties are destroyed. Systems thinking discourages reducing or simplifying life, instead viewing the life as a whole rather than a sum of its parts. Systems thinking also advocates taking context into account and promotes moving into more contextual thinking and away from analytical thinking (Capra, 1996).

Capra believes this more holistic way of viewing life has filtered down into other fields also. We see the development of quantum physics as a way to describe physical phenomenon by viewing the whole (1996). Instead of distilling down into single atoms or molecules, quantum physics was more likely to look at physics as an entire system (Capra, 1996). Quantum physics demonstrates a departure away from this traditional reductionist way of thinking about systems.

Ecology, meaning the study of the Earth Household, presents a holistic view of the environment and all of the living organisms and systems living there within (Capra, 1996). Ernst Haeckel formally defined ecology as the relations between organisms and the surrounding world (Esbjörn-Hargens & Zimmerman, 2009). This new view not only incorporated organisms and the workings of their systems but also the abiotic environment and how those living things function within that environment. This view also utilizes part of the systems thinking by viewing organisms and their environments as a functioning unit, unable to separate living from non-living components. This was essential to the development of a systems view of the environment. The terms ecosystem and biosphere also developed out of this view of the world. Through ecology we now not only view an ecosystem as organisms within a larger environment, but we can also see the organisms themselves as ecosystems. The inner workings of an organism are complex and interrelated systems that should be viewed together in order to appreciate the whole. Ecology is essential to understanding about networks and how different parts of the living world work and function together to create an inclusive whole (Capra, 1996).

The ontology of ecology parallels the ideas expressed in Capra’s book and views truth as flexible. Truth therefore is an approximate; it can only be assessed in parts through a variety of ways. Science is not the only way to assess truth and truth can be understood through a connection of humans to the natural world (Capra, 1996).

The epistemology of deep ecology suggests that when investigating the natural world, one can learn about phenomena through a spiritual connection to the environment (Capra, 1996). Knowing and being a part of the environment are the ultimate questions being considered (Capra, 1996). Understanding our own biology and moving away from a more anthropocentric view can free us to know truth. Truth is really an approximation; we can get close to it, but never really know it exactly. This philosophy aligns with the idea of inter-objectivity, or obtaining knowledge through our connection to the world around us (Capra, 1996).

The philosophical and epistemological underpinnings of ecological thinking

Capra stated that ecological thinking allows us to incorporate ourselves into the larger whole that is the biosphere (1996). Followers of ecological thinking support decentralization and the breakdown of industrialization. This would involve moving away from some of the traditional practices in industry of placing profit first and instead consider the affects on the environment or other organisms first. Returning to simpler more traditional ways, like smaller farms, having fewer children, and reducing consumption would support the deep ecology movement.

The creation of ecoregions, or areas that incorporate physical, biological and human components in a defined area, would also support an ecological way of thinking. A reduction in authoritarianism is also a major tenant of the ecological thinking movement. Ecology differs from more shallow environmental thinking, which focuses more on the short term and is known for being predominantly anthropocentric (Capra, 1996). For example, how will preserving the environment help people now and in the future? As opposed to the more ecological view, how does this construction affect the environment, other organisms living in the environment, and the humans living here too?

Epistemology of the deep ecology movement promotes ideas such as ethics in research, the value of diversity and the fundamental need for democracy (Capra, 1996). Deep ecology is rooted in inter-objectivity and accesses truth through action and knowledge through interconnections with the environment and other organisms. Other forms of philosophy rooted in the deep ecology epistemology include ecofeminism, ecopsychology and ecospirituality (Capra, 1996). All of these forms incorporate the environment as a fundamental part of healthy, well-rounded, human living.

Philosophy and methodology associated with ecological thinking

Deep ecology relies of more experiential methods of knowing. Learning by doing, observation, and experimentation are all ways of knowing about the universe. Arne Naess (1973) further developed the initial area of ecological thought into the more specific field of deep ecology. Naess supported ecological thinking as a way of life, not just an abstract philosophy and encouraged moving away from thinking in ethics and instead thinking in terms of ontology. Naess also supported a view of the world as a whole and humans as merely a piece of that whole. In order for people to fully realize deep ecology as a new means of understanding Naess (1973) developed these eight principles (Table 1).

Naess' eight principles of deep ecology illustrate to people directly how they can integrate ecological thinking into real-life scenarios. While some more abstract philosophies seem to lack real-life applications of the principles posited, the ecology movement touts a deep well of followers and practical ways to apply the philosophies presented. Many see the holistic view of all organisms and the environments that they utilize as the future of modern thought.

Table 1. Naess' principles of deep ecology (1973, pp. 95-98)

Principle	**Meaning of the Principle**
The well-being and flourishing of human and nonhuman life on Earth have value in themselves. These values are independent of the usefulness of the nonhuman world for human purposes.	This part would involve a complete paradigm shift, causing humans to see life and the environment in general as valuable entities regardless of whether or not they benefit humans. May show a major limitation in the implementation of deep ecology in that this conflicts with many major religion's ideologies.
Richness and diversity of life forms contribute to the realization of these values and are also values in themselves.	Promoting biodiversity as a simple value in itself. This can be difficult to promote since there is a lack of understanding of the importance of biodiversity.
Humans have no right to reduce this richness and diversity except to satisfy vital human needs.	Humans should respect this biodiversity and make efforts to preserve it. Still what qualifies as vital human need?
The flourishing of human life and cultures is compatible with a substantial decrease of the human population. The flourishing of nonhuman life requires such a decrease.	Major component of the movement. This attempts to limit or reduce the human population or future growth of the population. Again may conflict with a religious view that promotes human proliferation as a means to fulfill God's word.
Present human interference with the nonhuman world is excessive, and the situation is rapidly worsening.	Overpopulation, overconsumption, habitat degradation, pollution, urbanization of habitat and the introduction of non-native species, and the alteration of nutrient cycles are all ways in which humans have and continue to interfere with the non-human world.
Policies must therefore be changed. These policies affect basic economic, technological, and ideological structures. The resulting state of affairs will be deeply different from the present.	People would have to consider every action before undertaking it, and weigh the repercussions on the natural world. This would start with incorporating a new respect and equality of life into the education system.
The ideological change is mainly that of appreciating life quality rather than adhering to an increasingly higher standard of living. There will be a profound awareness of the difference between big and great.	This is one of the fundamental parts of Buddhist philosophy. Learning to be happy with less, and appreciating what we already have, does not come naturally to most.
Those who subscribe to the foregoing points have an obligation directly or indirectly to try to implement the necessary changes.	This places the obligation directly on the followers of this philosophy. Many people do not directly agree with all of the tenets here. Because of this, it would be difficult to ever realize the full effects of deep ecology.

The deep ecology movement has also spurred educational researchers to examine how we teach children about sustainability, and whether or not we are promoting some of the basic tenets of deep ecology such as diversity, ethics, egalitarianism, holism, collaboration and democracy. Dr. Stephen Sterling (2001) from the University of Bath has researched the changing educational landscape and has commented:

> The idea of 'education for sustainable development' is clearly moving up the Government's policy agenda but most education policymakers and practitioners remain unaware of the scale of change needed if education is to help Britain become a more sustainable society... The daunting challenge of achieving a sustainable society in the coming decades demands a wholesale and urgent reorientation of educational vision and practice (Sterling, 2005).

Sterling has also commented on the future of education and how not adopting a more holistic view in practice and in research could be detrimental to the futures of our students.

> Society's movement towards sustainability is a profound learning process involving everybody engaged in education, and one we are collectively still only in the early stages of...There is a real opportunity now to develop a new holistic vision in education, affirming its vital contribution towards a more liveable (sic), fairer and ecologically sustainable future (2005).

Sterling firmly believes that education must incorporate a much more ecological way of thinking and incorporate a more holistic view or else it will become part of the problem. Education is the key to producing new environmental stewards for the planet. This reveals a critical point where education may need to reconsider its own priorities in teaching core curriculum subjects and in how those subjects are taught (2001).

The possibilities and limitations of using ecology

My personal thoughts on using ecology as a means of not only better understanding the earth's process but also understanding our place in the environment can be beneficial in a number of ways. For example, moving away from an anthropocentric way of thinking to a more holistic view of the environment and where humans fit in that picture, may result in people placing greater value on other living things than they had in the past. This paradigm shift focuses more attention on other organisms and places greater responsibility on humans as organisms that can exert an enormous amount of control over their surroundings.

This paradigm shift would cause humans to view themselves as not only a part of the ecosystem, but no better than the other organisms within the ecosystem. Humans, since having an enormous capacity to alter their own environments, would be forced to consider every alteration to the environment in terms of it’s affect on other organisms. Also developing more contextual less analytical ways of looking at living systems would mean major changes in governmental, business and organizational policy.

There have also been a number of critics of the ecology movement. One of the biggest problems I would expect would be in instituting a new system, not everyone would follow in these philosophies. If even one person refuses to respect the process then the whole system might collapse. People would need to see a clear value in devaluing themselves and placing other organisms at a higher value. I would also expect a number of people, who due to fundamentalist beliefs, may have religious objections to any devaluation of human life.

Another drawback to an ecological view of living things is the idea that other organisms are not themselves centric. Daniel Quinn (1992) suggests that other organisms are also hampered by a centric view of the world, looking at the environments as a place for exploitation and a means to advance themselves. In fact, this seems to be the case in many systems, true altruistic behavior, that which receives no benefit for the one who is performing the action, is nonexistent in animal societies. This illustrates one of the misunderstandings about the natural world that might be incorporated into the deep ecology ideologies.

Researchers such as noted environmental ethics expert Bryan Norton, contend that a completely non-anthropocentric view of living things is a hopeless quest (1991). Norton posits that a modified shallow view of ecology is more realistic (1991). Teaching humans how to place greater value on the organisms around them and reduce their consumption, and degradation of those organisms is a reachable goal. Still, recognizing aspects of a reductionist way of thinking can be useful in certain disciplines. For example, developing a new cancer medication may focus on the effects of that medication on cancerous cells. To start this investigation a reductionist view may be necessary, then after the initial experimentation is completed, then a more holistic view could be taken and include other implications of the treatment. This method may allow for greater flexibility in the application of Capra's (1996) ideas to the word at large and insure that some progress be made in having humans place greater consideration on other organisms.

The current state of deep ecology

Based upon personal communication with many of the educators and biologists present at the Ecology and Education Summit on Environmental Literacy for a Sustainable World in 2010, there is still a great deal of disagreement as to what actually constitutes 'ecological' or 'environmental' literacy. The participants at the meeting, all coming from different backgrounds, seemed to each have their own take on what was most important in ecological literacy. One feature that continuously reoccurred throughout the meeting was the necessity of greater consensus and full-scale development of methods to address this issue. Some of the most important and critical areas in need of attention are described here. To compile these areas I have analyzed and expanded on information gathered from Ecology and Education Summit on Environmental Literacy for a Sustainable World, David Orr's book *Ecological Literacy* (1992), Kenneth Klemow and the Ecological Society of America's basic ecological literacy recommendations (1991), and Fritjof Capra’s essential principles of deep ecology (Center for Ecoliteracy, 2004).

In an attempt to synthesize and distill all of these ideas down into a more manageable package, I have created this list of ecological concepts essential for sustainability in future generations. This first is a list created by the Center of Ecoliteracy. It follows closely the most essential principles of Fritjof Capra and the deep ecology movement (Center for Ecoliteracy, 2004).

Networks - all living things are interconnected through networks within an ecosystem. These interconnections can be represented by food webs or trophic feeding levels. Disruptions to these links or interconnections can affect other levels within the system. These interconnections are frequently disrupted by the activities of humans. An emphasis on the links that humans have to other levels within the ecosystem in which we live is essential to engendering a sense of responsibility (Center for Ecoliteracy, 2004). Moving away from an anthropocentric world view where humans can use the environment to only satisfy their own purposes to a more ecocentric world view is critical to fully incorporating the concept of networks (Center for Ecoliteracy, 2004).

An ecocentric view sees humans as an integral part of the ecosystem (Center for Ecoliteracy, 2004). With this view we are unable to distance ourselves from the environmental problems at hand since we are not only a possible cause of these problems but we are very likely to be directly and indirectly affected by them. Placing ourselves back into the ecological network is one of the first steps to improving ecoliteracy in our current and in future generations.

Examples of networks in biological systems might include, pollinator and plant interactions, predator and prey, and various feeding webs (Center for Ecoliteracy, 2004).

Nested Systems - networks emphasize the existence of interconnects in nature. These networks are all part of larger systems. The systems we see in nature are part of larger systems and within them are smaller systems (Center for Ecoliteracy, 2004). Various parts make up a whole in nested systems. Changes within one system can not only affect the other smaller systems nested within that larger one, but may also adversely affect larger systems that that system nests within (Center for Ecoliteracy, 2004). Examples of this would be the hierarchy of natural systems: atoms→ molecules→ cells→ tissues→ organs→ organ systems→ organism→ populations→ community→ ecosystem→ biosphere.

Cycles - ecological communities continually exchange resources within global systems (Center for Ecoliteracy, 2004). Although the resources we use here may appear to only be affected by local conditions, they are still part of larger systems. The hydrologic cycle is a good example of the interconnectedness of all the water on the planet. Water that runs through a garden at the local level is still part of a larger global system, and still being subjected to evaporation, condensation and then precipitation. Contaminating water in one locale may have compounded effects in other areas that depend on that same water, as we see in the pollution of rivers that service many communities. Understanding the cycling of natural resources such as water, nitrogen, and carbon can greatly improve how can learn to use our shared resources wisely.

Flows - flows in natural systems categorize how energy is converted from one form to another (Center for Ecoliteracy, 2004). One of the requirements of life is energy; and all living things require energy in some form. In living systems energy is continually being converted from one form to another. With every conversion some energy is dispersed in the form of heat requiring a constant replenishment of energy. Newton's First Law of Thermodynamics applies to this phenomenon: Energy cannot be lost or destroyed but only changes form. Understanding natural systems and how energy flows through those systems is critical to recognizing how these systems can be influenced by human actions (Center for Ecoliteracy, 2004).

Plants and other autotrophic organisms are a major key to flows in systems. Autotrophic organisms have the ability to convert non-living energy, such as solar, into chemical energy, such as glucose. Autotrophs are the bottom of every food web, which means that disturbance at this trophic (feeding) level is likely to affect the flow of energy in higher trophic levels. Understanding how energy flows through our ecosystem can better help students understand how vital plants and other autotrophs are to the other heterotrophs, like humans, within a system. Sustaining biodiversity at lower trophic levels will directly and indirectly help support biodiversity at higher trophic levels (Center for Ecoliteracy, 2004).

Development - development signifies changes over time (Center for Ecoliteracy, 2004). This concept is most fully realized in the theory of evolution. Evolution is considered a foundational theory for the field of biology. Living things show development at different levels of organization; as an individual, a species, a community, an ecosystem. Individuals can show development as adaptation and learning in response to changing natural systems. A species can adapt as a whole when conditions change within their habitat. Populations within an ecosystem can experience co-evolution with other species. We see good examples of this when looking at co-evolution between predators and prey. For example: wild hares show better camouflage when wolves become more successful hunters.

Dynamic Balance - dynamic balance means that ecological systems can be maintained even in light of some fluctuations (Center for Ecoliteracy, 2004). Ecological communities function with natural, internal feedback loops providing some flexibility with the system (Center for Ecoliteracy, 2004). This balance means that cycles develop within almost every natural system and that overall balance is maintained through an ebb and flow of resources.

For example, as a population of wolves increases, possibly due to better hunting tactics, they start consuming more wild hares as food. When the population of wolves increases, then the population of hares decreases inversely with the increased predation. Once the habitat's carrying capacity has been reached for the wolves they will start to die back, due to reduced access to habitat and fewer hares to consume. Because of the reduced number of wolves the population of hares will rebound now providing food for more wolves which in turn will cause an increase in the population of wolves. This cyclical process occurs in almost all living systems and can continue indefinitely (Center for Ecoliteracy, 2004).

David Orr suggests, along with the Center for Ecoliteracy, that one important way to promote ecological literacy, which can ultimately lead to a green society, is to create a more systems based classroom (Center for Ecoliteracy, 2004; Orr 1992). Orr feels that this approach to learning should be incorporated in every class, not just undergraduate education and not just in the sciences (1992). Moving to this more holistic approach better emphasizes the importance of interconnections within every field of study and between fields of study. Starting with even the youngest of students develops more well-rounded learners capable of showing flexible learning and developing meaningful webs of knowledge.

Recently there has been increased interest in newer learning styles. Learning across the curriculum and service-learning are some of the newest techniques being advanced in support of improving learning at the K-12 level and in post-secondary education (De Stasio, Ansfield, Cohen, & Spurgin, 2009; Wyss & Tai 2012). A systems perspective not only encourages a more holistic and ecological way of thinking it is also a good way to interweave topics in various disciplines and promote learning through service as shown through environmental justice issues.

The systems perspective is another lens through which one can view and better understand a complex world. The systems perspective can be broken down into these key comparisons to better conceptualize what a systems-based classroom may look like as opposed to a typical classroom. Note that these key points run along a continuum and are not truly contrasting alternatives.

<u>Parts to a Whole</u> - moving away from a reductionist perspective to a more holistic view is one step to shifting focus from pieces to wholes (Center for Ecoliteracy, 2004). For example, instead of having students draw the parts of a honeybee, take the class to a garden to draw the honeybee in its natural habitat. Here the students are encouraged to think about how the bee gets food, finds shelter, and survives through seasonal changes. This activity could incorporate anatomy of the bee, botany of the plants, ecology of the food web, physics of their flight patterns, seasonal change as earth science, or the mathematics of optimal feeding strategies. Even beyond these direct lessons that could be interwoven from this type of experiential, outdoor learning, there are other indirect lessons that can also be created to emphasize this more holistic view.

<u>Objects to Relationships</u> - in systems thinking, the study of objects or things is secondary to the study of the relationships between the objects (Center for Ecoliteracy, 2004). These relationships between objects can be more important than the objects themselves when using the systems lens (Center for Ecoliteracy, 2004). For example, when teaching a lesson about

ecosystems we would need not only to examine the individual species within that system, we would want to know more about how each of those species interact in that system. Through the systems lens, the "objects" of study are the relationships (Center for Ecoliteracy, 2004).

In a classroom setting this can be simulated through an emphasis on consensus and cooperation (Center for Ecoliteracy, 2004). How the classroom "works" or moves forward relies heavily on the relationships that are built between the students and with the teacher (Center for Ecoliteracy, 2004). This perspective tends to emphasize relationship-based processes in natural settings and within the classroom.

<u>Objective Knowledge to Contextual Knowledge</u> - switching from an emphasis on the study of objects to the study of relationships also lends itself to development of contextual knowledge (Center for Ecoliteracy, 2004). Overtly analytical and reductionist thinking tends to break systems down and examine individual parts. Contextual thinking builds on the idea of emergent properties; some aspects of a phenomenon can only be revealed when looking at a higher level of organization (Center for Ecoliteracy, 2004).

In the classroom, building contextual knowledge can be accomplished through the use of more project-based and inquiry-based learning. Having students examine problems, explore the background of the problem, and develop questions about the problem, and means to address the problem can be a valuable and enjoyable lesson that sustains content knowledge. This method would also support teachers acting more as facilitators and as fellow learners with the students rather than acting as experts dispensing knowledge. Not only does employing techniques like this improve long term retention, but it also helps to develop students as inquisitive, self-motivated learners as opposed to the filling empty vessels method.

Quantity to Quality - Descartes was one of the first philosophers to emphasis reducing phenomena and measuring them in order to better understand how they work. While this method works to simplify and to aid in the comprehension of some very complex subjects, there are some phenomena that cannot be fully understood this way (Center for Ecoliteracy, 2004). In essence, there are many aspects of science that cannot be measured completely, such as an ecological food web. A food web represents feeding connection between a variety of different species with a habitat. Here this system instead of being measured may be better understood visually though images and mapping (Center for Ecoliteracy, 2004).

Structure to Process - understanding a systems perspective shifts the focus of a lesson from specific structures to entire processes (Center for Ecoliteracy, 2004). Processes that might get special attention would be evolution, renewal and change. Engaging students in nature as a dynamic process helps them develop a more fluid grasp of systems. School subjects are continually under development, refinement, and modification. These are processes that students should embrace and incorporate as an important part of learning about a topic and teachers should strive to implement as practice. In the classroom this would mean emphasizing the problem solving process more than the right answer (Center for Ecoliteracy, 2004). The actual process used to come to a decision is key and vital to future good decision making skills, verses the decision itself.

Contents to Patterns - when using a systems lens, teachers can facilitate and learners can internalize insight into many diverse fields, not just one area of expertise (Center for Ecoliteracy, 2004). Some systems show the same types of patterns and these may be generalized to understanding how many systems might work. A good example of this could be grasping the understanding how energy flows through a natural system and that may mimic how information flows in a social system (Center for Ecoliteracy, 2004). Seeing the bigger picture can help guide understanding in both systems and draw more interdisciplinary collaboration.

Ecological Literacy as Examined by David Orr

In Orr's book, *Ecological Literacy* (1992), he pinpoints six key foundations used to answer the question, " What does it mean to educate people to live sustainably?" There is a growing impetus that the children who enter our schools not only leave as well-educated adults but that that education also includes the knowledge and tools to sustain, improve, and acknowledge the natural world we live in. These six key points better illustrate how ecoliteracy starts at birth and requires continual learning and flexibility (Orr, 1992).

Orr states, "All education is environmental education" (Orr, 1992, p. 90). This is Orr's first point of emphasis in the formation of ecologically literate students. He proceeds to explain this principle, "By what is excluded, emphasized, or ignored, students learn that they are a part or apart from the natural world. Through all education we inculcate the ideas of careful stewardship or carelessness." (1992, p. 90). David Orr makes an excellent point here being very critical of the entire way in which we choose to educate the next generations. Orr feels that the way we teach our students in all areas, not just the sciences, can engender a sense of responsibility, community, and interconnectedness with all things living or non-living (1992). Likewise, educators can teach students anthropocentrism, selfishness, and separatism, implying that the environment is only here for human use and consumption. According to Orr, this holds true at every grade level and in every subject (1992). Sustainability literacy for students begins with ecoliteracy for every teacher.

Orr's second principle for understanding ecological literacy states, "Environmental issues are complex and cannot be understood through a single discipline or department" (1992, p. 90).

Orr presses educators to recognize that earth-centered education required collaboration across and between departments (1992). He also acknowledges that interdisciplinary education and research is still a largely unfulfilled promise touted within our traditionally structured education system (Orr, 1992). Orr suggests that in order to met this goal we need to consider restructuring the educational system out of the traditional, reductionist departments, and instead look at problem-based ways of educating that would involve multiple subjects at once. While the idea of restructuring the current education system that drastically is unlikely to occur anytime in the near future, still, taking a problem-based focus towards science classes may help better integrate seemingly disparate ideas for our students. Problem-based learning is also immersive and strongly encourages independent thinking, problem solving, use available academic resources, and collaboration with peers (Orr, 1992).

Orr's third principle explains, "For inhabitants, education occurs in part as a dialogue with a place and has characteristics of a good conversation" (1996, p. 90). Educators are learning that good education does not view the student as a blank slate, or tabula rasa (Orr, 1992). Students come into the classroom having already been shaped, influenced and affected by their own experiences. Previous teachers, parents, peers, and personal experience can and frequently do provide the scaffolding for which we are to build upon. Even if that scaffolding does not stand up to new information, our students will frequently try to integrate new information with what was previously acquired, no matter how dissonant those ideas may be (Orr, 1992).

Including students in the education process is key for true synthesis and long-term learning to occur, according to Orr (1992). Learning opportunities can be created in the classroom by using conversational techniques and building a dialog with students. Some of the ideas that are most memorable to students, and even easiest to understand, are those that have been presented in a less dictatorial manner. Building a conversion with students is an excellent way to show them that the education process is a two-way street and requires their input also.

Likewise, when teaching about the environment we should be able to place ourselves within the environment as an integral part of the ecosystem (Orr, 1992). As a part of the ecosystem we recognize that we are a part that can affect and can be affected. Orr suggests changing the language we use when teaching about the environment. Eliminating the use of words such as 'resources', 'manage', 'engineer', and 'produce', creates a monologue and not a conversation between people and the needs of our environment. To create a dialogue people need to place themselves back into the ecosystem instead of apart from it. People need to instead ask questions like, “What is here?” or “What will nature permit here?” and “What will nature help us do here?” (Orr, 1992, p. 91). These questions instill a sense of interconnectedness with the natural world and an ultimate sense of responsibility for our actions.

In Orr's fourth principle he claims, "The way education occurs is as important as its content" (1996, p. 91). He explains, “Environmental education ought to change the way people live, not just the way they talk.” (Orr, 1992, p. 91). This very powerful statement by Orr eloquently sums up how we as educators are still missing the mark when it comes to educating students to be thoughtful consumers. By teaching environmental awareness in a setting that clearly displays our lack of regard for the environment in which we live, they learn more than what we intentionally teach. Students learn that being environmentally literate simply means that you can intellectualize and theorize about the situation without actually making any personal modifications in how we live (Orr, 1992).

Orr claims that becoming environmentally aware means not only learning the concepts in the classroom, but broadening that understanding and applying it to the issues that directly and indirectly affect the local community. "Real learning is participatory and experiential, not just didactic" (Orr, 1997, p.91). When in the classroom, educators tend to draw sharp lines between teacher and student, classroom and school, school and community, etc. (Orr, 1992). When creating these boxes it is easy to forget that the purpose of education is not only to fill our student's heads, but to make them more capable of dealing with real world issues. These lines of distinction need to be blurred in order to allow students to experience real life problems and the types of things that may affect their quality of life, and the environment in which they live (Orr, 1992).

Furthermore, teachers too, should model the behavior they most hope their students will emulate (Orr, 1992). Students learn much more from what we do than just what we say. If we teach about the value of recycling and then refuse to purchase recycled products then there is a disconnect. Teaching students about service learning, environmental justice and the like is not good enough. We should be showing them that these issues are not only important enough to talk about in class but important enough to dedicate our time, money, and energy towards finding a solution.

Orr's fifth principle, "Experience in the natural world is both an essential part of understanding the environment but also conducive to good learning" (1996, p. 91). According to Orr, direct experience in the natural world not only allows one to develop a better natural sense but can also be vehicle of thought, as Emerson once said (1992). Poets, writers, artists and philosophers have gone to nature for respite and as a source of inspiration. Biodiversity itself can be a teaching tool and can encourage creativity in thinking. Also a number of studies attest to students learning better in outdoor setting which can be relaxing or refreshing (Orr, 1992).

Building environmental studies into an outdoor setting or an outdoor classroom would lend itself to increased environmental awareness and appreciation.

The last of Orr's principles states, "Education relevant to the challenge of building a sustainable society will enhance the learners competence with natural systems" (1996, p. 92). Orr suggests that connecting real problems with theoretical ones from the classroom supports good thinkers (1992). Developing this practical competence will give students yet another tool to go to when faced with real problems as adults working within our very real systems. Overall systems thinking connects the abstract with the real and emphasizes the loops that we find in every system we encounter (Orr, 1992). Sustainability is not just the job of government officials or businesses, it is the job of every person to work toward conserving our environment and those resources on which we rely.

Edward Tufte and Information Display

Printed educational material in the form of laboratory manuals and textbooks can greatly influence not only how and what students learn but can also influence how and what instructors teach in a class. Most popular textbooks have been created using a standard reductionist style. Creating more ecologically literate students not only involves altering teaching techniques and material but it may also involve reconsidering how our textbooks are written. Textbooks should be evaluated not just for systems thinking elements but also of the emphasis placed on systems as opposed to individual facts concepts or vocabulary. The cycles and flows naturally evident in natural systems should also be demonstrated through scientific writing (Center for Ecoliteracy, 2004).

Yale University Professor, Edward Tufte, is best known for his work in information display. Through his four volume books on the theory of information architecture, Tufte has set the standard for how to best display even the most detailed and technical of information (Tufte, 1990, 1997, 2001, 2006). Table 2 contains Tufte's main principles.

Table 2. Tufte's display principles

Show the data
Avoid distortion
Maximize data ink
Avoid chart junk
Have a clear purpose
Clarify large data sets
Use multi-variate displays of data to organize large data sets
Use data along with written descriptions
Reveal the data in layers and create depth

Tufte (1990, 1997, 2001, 2006) suggests the primary purpose of a data display is to better show the data. He recommends avoiding misrepresenting the data by cherry-picking a few key features and ignoring the rest, or drawing graphics for comparison that lack proper scale. He also recommends using graphics that display the data as clearly as possible with the least amount of data ink. In addition, fancy pictures or elaborate drawings to grace the edges of a graph are unnecessary and distract from the main purpose of the graph.

Another consideration Tufte posits is the obvious purpose of the graph. He cautions that when working with large amounts of data it is easy for the reader to get lost and reminds scholars that the job of the researcher to properly organize the information that it can be understood as clearly as possible. Proper legends and labeling can go a long way in clarifying data, according to Tufte. Sometimes combining written descriptions with data is necessary to explain what needs to be emphasized in a graphic. Finally, showing data in small scale and then moving up to a larger scale might be a nice way to see not only the finer details but also the whole picture. For example, Google Maps does this by allowing you to see an actual photograph of the business's building you are searching for, and then you can zoom out of the image in order to see directions of how to get there.

Another technique that Tufte developed as a means of better displaying some types of information is the use of small multiples (Tufte, 1990). Small multiples can be greatly useful when displaying different graphics that have subtle differences. Placing a large number of them together makes comparison easier. For example, a clothing catalog might place all the colors of their t-shirts onto one graphic so that one might be able to better compare the different color combinations. This technique is similar to parallelism can also be used to compare similar data (Tufte, 1997). Placing individual graphics side by side so that similarities and differences can be accentuated is a excellent tactic for drawing attention to small details.

Tufte also advocates the use of macros and micros (Tufte, 1990). Some data lend themselves to the use of both a macro and a micro graphic. Using large graphics with smaller ones can better represent large data sets but can also create depth. Additionally, sparklines were created by Tufte (2006) to convert data into small intense word-sized graphics. Sparklines can represent data that may change rapidly over a period of time, like a machine that charts heart rate over a period of time.

From my perspective, I feel that students would benefit most from visual information presented in way that utilizes Tuftian principles. Textbooks may better transmit information by utilizing some of these techniques in graphics and other visual representations. Seeing this as a potential benefit to students and to the science learning process should drive educators to improve the ways in which we display information in our textbooks and in our classrooms. Developing ecological and scientific literacy in our students could be helped by developing more visually appealing data delivery systems.

Formulating Methods: Quantitative, Qualitative, and Mixed Methods Research

Selecting the research design that is appropriate for your particular study depends largely on needs, questions, and goals (Johnson and Christensen, 2008). To a certain degree an appropriate design also depends on the type of information your stakeholders expect. There are benefits and drawbacks to each of the research design types, quantitative, qualitative, and latest addition, mixed methods. Careful consideration of the appropriate research design can help produce the most meaningful and valuable results possible.

Quantitative Research

Quantitative research involves collection and manipulation of numeric data (Johnson and Christensen, 2008). A quantitative study could be something that involves a survey or a direct experiment that generates data primarily in the form of numbers. The data collected from quantitative research can be easily summarized and analyzed using statistics. Quantitative research generally follows a deductive form of the scientific method (Johnson and Christensen, 2008).

There are also two primary categories of quantitative research, manipulated and non-manipulated (Johnson and Christensen, 2008). A manipulated study might be classified as a 'true experiment'. A manipulated study might use an intervention in order to test whether or not that particular intervention has an effect. A non-manipulated experiment might use a survey to assess student’s feelings about an aspect of a course. Both of these study types would be considered quantitative because they both generate numeric data. Regardless of which type of quantitative research is used, there are still some pros and cons to using this technique (Johnson and Christensen, 2008).

Possible benefits of strictly using quantitative research are that qualitative research tests theories and hypothesis that are generated a priori. A well conceived hypothesis can help guide the progression of the research. Quantitative research can also generate hypotheses that may be generalizable to larger populations if a large enough sample size is used. Likewise, data may be generalizable to other populations if there are a wide variety of diverse groups included in the sampling.

Another benefit of using quantitative research is that this type of data can be manipulated to control for potential confounds, thus increasing the possibility of establishing causation. Quantitative data also tends to lend itself more easily to statistical analysis. Computer programs such as SAS and SPSS can be used to analyze data relatively quickly and easily. Using a technique like as a telephone survey and analyzing with statistical software could generate a large amount of data in a short period of time. For these reasons quantitative research is also generally less expensive to conduct.

Finally, quantitative research is easier to use when sampling large populations. It is very difficult to adequately sample very large populations using qualitative research methods alone. For this reason quantitative research may also be more easily and readily accepted by stakeholders, politicians, and the public. Researchers should select an appropriate research tradition and technique that addresses research questions and meets the expectations of stakeholders. Even in light of these benefits, there are some limitations to using strictly quantitative research (Johnson and Christensen, 2008). For example the hypotheses being tested may not be well understood by stakeholders, thus the information goals of the researcher need to match the goals of stakeholders. Likewise, quantitative research may miss valuable information by focusing too heavily on the hypothesis testing and not enough on hypothesis and theory generation.

Another potential drawback of the quantitative style is that the specific testing method used may be too abstract or broad to be applicable to specific cases. Also, quantitative data does not demonstrate context. This is a valuable part of the puzzle for many research questions. This can produce results that are two-dimensional, lacking the richness and depth that is produced from qualitative data.

Qualitative research

Qualitative research is different from quantitative research in that it focuses on data that is non-numeric, such as pictures or words (Creswell, 2007; Johnson and Christensen, 2008). Some common types of qualitative research include phenomenology, grounded theory, history, case study, and ethnography (Creswell, 2007; Johnson and Christensen, 2008). There are five distinct traditions of qualitative research. Presented here are some brief descriptions of each of these distinct types of qualitative research: phenomenology which centers around an individual or a group of individuals' experiences with a particular phenomenon (Johnson and Christensen, 2008); ethnography which translated literally means "writing about people" (Johnson and Christensen, 2008; Creswell, 2007); case study, a style of research giving a detailed account of one or more specific cases (Johnson and Christensen, 2008; Merriam, 2009; Stake, 2010;Yin, 2009); narrative research, used to describe people, events or places from the past (Johnson and Christensen, 2008) and finally, grounded theory, an approach concerned with developing a theory or an explanation of why something operates the way it does based on data that have been collected (Johnson and Christensen, 2008). Some such as Creswell (2007) use the term historical research as a tradition of qualitative inquiry versus Johnson and Christensen's (2008) use of narrative. Further, the form of the qualitative method termed as narrative has developed into a distinct method of inquiry as defined in detail by Clandinin (2007); Connelly & Clandinin (1990); Gudmundsdottir (1997; 2001) as very distinct from historical research (Johnson and Christensen, 2008.

Selecting the appropriate style of qualitative methodology is just as important as the research itself. Koro-Ljungberg et al. (2009) suggests that epistemological awareness in research is just as important as the research itself and must be clearly and transparently communicated to the reader of the research. Koro-Ljungberg et al. (2009) present a valid argument in showing how lax many researchers have been in explaining the theoretical and epistemological grounding of their work. Demonstrating this understanding of one's own research is essential when presenting qualitative work.

Others have proposed methods of selecting an appropriate qualitative technique such as the "Five Question Method" suggested by McCaslin and Scott (2003). McCaslin and Scott (2003) suggest many researchers struggle with developing a proper frame for the study they are conducting. They describe how many qualitative researchers fail to properly form a problem statement or a purpose statement and ultimately do not fully form a grand tour question (McCaslin and Scott, 2003). This five-question method could help simplify the process of research development and increase the likelihood of selecting an appropriate method before undertaking the research itself.

Qualitative research tends to generate richer, more detailed data, but statistical analysis is frequently unlikely or impossible (Johnson and Christensen, 2008). Qualitative research tends to follow a more inductive form of scientific method (Johnson and Christensen, 2008). Similar to quantitative research, there are limitations to using a strictly qualitative research design. Burke

Johnson and Larry Christensen detail some of the potential benefits of using the qualitative style (2008). Johnson and Christensen describe how qualitative research can be selected to best match the type of information desired and research questions may be guided by during the collection of data (2008). Research questions can also be modified throughout the course of a qualitative study. Likewise, qualitative research can be modified or even shift focus if problems are encountered during a study (Johnson & Christensen, 2008).

Furthermore, qualitative research can generate data that is rich and detailed giving an intimate perspective of a particular issue. One of the ways in which qualitative research can do this is by preserving context. Natural settings are frequently maintained during qualitative studies and that context can greatly shape the outcome of any research.

Lastly, in qualitative research researchers delve into each individual data set collected and thus can draw out specific examples to dramatically illustrate a point when presenting findings. Qualitative researchers also allow individual participants and their data to be dynamic, and capable of showing change and fluctuations over time. Participants are not just reduced to a set of constructs, such as IQ, and can also be asked how they feel about those constructs. This technique provides new depth to some questions that may have only had one-dimensional data collected previously.

Even in light of all of these potential benefits Johnson and Christensen also discuss some potential limitations of using qualitative research (2008). In qualitative researchers are more likely to be influenced by personal feelings and bias, one must be aware these and acknowledge this possible limitation. Because qualitative research tends to focus more on specific examples and not very large groups, like in a case study, the data may show a narrow focus and this may not be generalizable to a larger population. Also unlike quantitative data, qualitative data is sometimes not analyzable through statistics. Qualitative research can be expensive and time consuming; some studies can take years to collect data for just one study. Stakeholders may not want to spend the time or the money on qualitative research.

Mixed methods

For these above stated reasons, researchers are showing increased interested in using both qualitative and quantitative research in conjunction in order to derive the benefits from both types of research (Johnson & Christensen, 2008). There are still some that insist that both methods cannot be used in conjunction and that the main focus of each method makes them incompatible (Johnson & Christensen, 2008). Still other researchers support the compatibility theory (Johnson and Christensen, 2008). This theory states that both qualitative and quantitative methods can be used in conjunction to benefit both sides of the research spectrum (Johnson & Christensen, 2008). Additionally, the fundamental theory of mixed methodology states that mixed methods can use both qualitative and quantitative research methods to maximize benefits from both and minimize non-overlapping drawbacks (Johnson & Christensen, 2008).

Mixed methods research can show the benefit of using quantitative data to add frequency and quantity to a qualitative study (Tashakkori & Teddlie, 2003). Sampling sizes can increase, leading to a greater possibility of generalizability. Qualitative data can also add richness and depth to a quantitative study. Descriptions of a few case studies can greatly add to the depth of a simple survey study. With mixed methods research, words can combine with numbers to better illustrate and explain data patterns and numeric data can be analyzed with traditional statistics creating a more complete picture of the issue being addressed. Ultimately, mixed methods research can allow for greater flexibility in generating and testing research questions and may help minimize some of the drawbacks of each of the other methods (Johnson and Christensen, 2008).

Although there are a number of benefits to using mixed methods research, there are also potential limitations (Johnson and Christensen, 2008). For example, mixed methods research requires the researcher to learn more about both qualitative research and quantitative research. Therefore, mixed methods can be considered more time consuming and at times more expensive than using qualitative or quantitative methods exclusively. Mixed methods may also require more than one person to complete the study, especially if the two parts are being run concurrently (QUAL & QUANT). Additionally, stakeholders may not accept mixed methods research; instead they may support the incompatibility theory (Johnson & Christensen, 2008).

The benefits of mixed methods research have begun to pave the way for more mixed methodology researchers. Using both qualitative and quantitative methods can create a depth of research that cannot be achieved through using one methodology alone. Still researchers may still feel that only one or the other of these methods alone is the best technique for examining research questions. The growing field of support for mixed methodology can be seen by the successes of these and many other such researchers (Creswell, 2007; Tashakkori & Teddlie, 2003).

In summary, throughout history we have seen the ebb and flow of different belief systems acting to shape our understanding of scientific processes and how well we seem to incorporate systems into that understanding. With the current declining state of our ecosystems, it would behoove us to find ways to educate our next generations with tools that can be used to improve instead of over-exploit our world. Systems based learning systems may help create more ecologically conscientious citizens. How can we gauge our student's ecological literacy? The research here attempted to address this question.

Chapter 3 Methods of Textbook Graphical Analysis

The focus of my dissertation research is on ecological literacy in the college classroom and particularly how that literacy can be better developed through the use of graphics that promote systems thinking. There is growing concern that students today are graduating from college with very little knowledge or understanding of the environmental and ecological problems facing us (Coyle, 2005). Even more alarming, is the idea that educators today are not doing an adequate job of equipping our students with the tools and skills they need to take actions that would improve environmental problems. Their conduct should reflect a sense of personal ownership and a basic understanding of what needs to be done to help solve growing environmental issues.

My plan for study was to develop a framework for assessing textbook graphics with regard to the incorporation of systems-based principles. I believe that textbooks are critical to an instructor for the development of a course. Instructors frequently follow the textbook to determine which topics get the most emphasis in class and to derive explanations for complex subjects. In many cases instructors rely heavily on textbook graphics to display during lectures or for use as examples during class. In this case, the quality of those graphics can greatly affect the depth of understanding in our students. I believe that it is essential for instructors to have access to and to utilize textbooks that can encourage the development of systems-based thinking and ecological literacy that ultimately lead to conscientious environmental action.

My view is that a lack of systems-based teaching greatly hinders development of true ecological literacy in our students. I also believe that having this type of understanding will make ecological literacy more likely to take root. Furthermore, students who show both ecological literacy and systems-based thinking when faced with environmental problems are more likely to make environmentally conscientious choices.

The previous chapters have established four primary points of concern. The first point of concern is that environmental problems here and worldwide have been increasing over the past decades especially since the Industrial Revolution. Secondly, the United States has been particularly culpable in the increase of these problems with regard to our ever increasing consumptive and wasteful lifestyles. Third, adults, whether old or young, seem to show low levels of ecological literacy and environmental action. Lastly, the majority of the American population believes that environmental education should be a part of formal education.

These four points help to highlight the nature of the ecological literacy problem facing educators. Even in light of these points there currently appears to be no means of assessing ecological literacy, especially one that incorporates ideas of systems thinking, in college students. Furthermore, much of what is taught in college classrooms tends to follow closely to that which is detailed in a small selection of popular textbooks. Based upon my personal experience having used a variety of textbooks in my teaching, almost all of these commonly used textbooks preliminarily appear to take a largely reductionist approach instead of a systems-based approach for presenting concepts, thereby significantly downplaying the essential nature of ecological problems.

Through this research I have developed a detailed means of assessing college textbooks for systems thinking and for the presence of ecologically-framed concepts. My primary goal of this research is to develop a clear picture of how much textbooks can help advance the development of ecological literacy in students. I considered the following research questions:

- What is a typical volume of graphic content within a sample of collegiate introductory biology textbooks that uses systems-based thinking?
- How do select popular, collegiate introductory biology textbooks better utilize a mixture of reductionist thinking and systems thinking through graphics?
- How many sample collegiate introductory biology textbooks use reader-centered graphics that correspond to classic Tuftian principles?

I feel that not only do researchers need a better means of analyzing content in this growing area of concern, but educators need to also become more critical of the role that textbooks can play in shaping our students. I believe that the incorporation of systems-based ideas into texts and lectures could improve ecological literacy and ecologically conscientious action. The first step to better understanding this issue is developing an appropriate method of content analysis for these textbooks.

Through this research I conducted a content analysis of the graphical content of a selection of several popular college level introductory biology textbooks. I present here a detailed analysis of the graphics in both the introductory and ecology chapters of the textbooks looking for the key features of systems-based thinking as described through Capra's writing. This included elements that might be classifiable in one of these six categories which represent the most essential principles of Capra and of deep ecology: networks, nested systems, cycles, flows, development, and dynamic balance. This analysis process was able to highlight either a largely reductionist approach or a largely systems-based approach. I hypothesized that most graphics will fall somewhere along a continuum between these two approaches. Since generally only a subset of biology majors ever receive any specific ecology training, and non-biology majors usually receive no ecology training at all, it becomes increasingly imperative to consider a more ecological tone in all general biology textbooks.

Textbook Sampling

Using the website Aaron Shepard's Sales Rank Express (2007) I searched for Amazon.com sales figures on the U.S.'s most commonly sold, college-level, general biology textbooks. Based upon this research I identified the first four textbooks listed in Table 3 that hold the highest sales rank. A lower number in the ranking column indicates a higher position on sales charts and therefore a greater number volume of texts sold. The Brooker et al. *Biology* (2011) textbook showed the highest overall ranking of any biology textbook sold through Amazon.com. Each Amazon.com sales rank includes all hardcover, paperback and eBook sales.

Table 3. Top college general biology textbooks shown by sales rank on Amazon.com

Textbook Title	Authors	Publication Date	Publisher	Sales Rank Amazon.com
Biology, 2nd ed.	Robert Brooker, Eric Widmaier, Linda Graham, Peter Stiling	2011	McGraw-Hill	25,127
Campbell Biology: Concepts & Connections, 7th ed.	Jane Reece, Martha Taylor, Eric Simon, Jean Dickey, Richard Liebaert	2012	Benjamin Cummings	35,039
Biology, 9th ed.	Peter Raven, George Johnson, Kenneth Mason, Jonathan Losos, Susan Singer	2011	McGraw-Hill	37,917
Biology: Life on Earth with Physiology, 9th ed.	Gerald Audesirk, Teresa Audesirk, Bruce Byers	2011	Benjamin Cummings	45,911
Biology	Jay Phelan	2010	W.H. Freeman	1,140,171

The first four of these listed books represent the most current, commonly required textbooks for college major and non-major classes. The last text by Phelan is a recent addition to the biology textbook market and is not yet as extensively used as the other four in comparison. I chose to include Phelan's text, *What is Life* (2010), because it is very different in style and emphasis. This book takes a much more relaxed and general approach than the others, at many times using common language and generally relatable examples.

Through my research I analyzed all the graphic components within the chapters that primarily include topics that might lend themselves to a systems-based view instead of a reductionistic one. Specifically, my research was to evaluate chapters dealing with introductory information and ecology (see Appendix A). These chapter topics were selected as being some of the most commonly used chapters in college-level, introductory biology courses that would benefit most from a systems perspective. These chapters are considered essential topics in introductory college biology.

Data Collection

As part of my research study, I developed three rubrics based on the guidelines outlined in Stevens and Levi's book, *Introduction to Rubrics* (2004), to use when assessing each of the graphics in these selected textbook chapters. The first rubric (see Appendix B), was created with a focus on addressing research question one. This question asks, "What is the typical volume of graphic content within a sample of collegiate introductory, biology textbooks that uses systems-based thinking?" To help answer this question I created this system-based rubric focusing on each of the six categories which represent the most essential principles of Capra (Center for Ecoliteracy, 2004) and the development of ecological literacy: networks, nested systems, cycles, flows, development, and dynamic balance.

I then scored each graphic based on the aspects of each principle as described in the following. Networks: An image that scored exemplary in this category strongly demonstrated ecological network connections by showing multiple organisms exhibiting the same phenomenon. There may have also been an inclusion of humans and human activities linking real-life actions and how those actions might affect other parts of the ecosystem. This is not simply an anthropocentric view but reminds the reader of other non-human connections within a network. An image that met only some but not all of these qualities was ranked as average. A graphic that only focused on a human perspective and did not show any linkages to other living things was ranked as weak and thus lowest in this rubric category.

<u>Nested systems</u>: A graphic that ranked exemplary at this principle showed multiple perspectives of the same phenomenon. When showing biological processes a graphic may have strongly demonstrated nested systems by including depictions at a cellular level, organ level, organism level and possibly the community level. A graphic that ranked average in this category might have displayed only two levels such as in a simple comparison instead of a range. A weak ranking indicated a graphic that only showed a single level such as in a graphic of a single cell or molecule.

<u>Cycles</u>: A graphic received an exemplary ranking in the area of cycles by incorporating before, during and after views of a process. Many biological processes are cyclical in nature and do not have beginnings or endings such as the cell cycle. Some graphics might depict this process as a straight line, directly linear event, this would have given the graphic a average ranking instead of emphasizing the continuity of this process in cells. A graphic that ranked weakest in this category might have only shown a single stage and not aspects of the entire cyclical process.

Flows: Graphics that demonstrated flows at the highest level showed both positive and negative results or effects of a phenomenon. These graphics demonstrated how humans are interdependent on their own habitats. Humans being just one component of an ecosystem will affect that ecosystem through habitat modification, use and consumption of resources, and production of waste products. These processes can negatively and positively affect an ecosystem and can be demonstrated as complex interactions through a depiction of ecological flows. Average ranking in this category would have only showed positive or negative effects and not both. Likewise, a weak ranking was earned for a graphic that failed to show any possible effects of a phenomenon, positive or negative.

Development: High ranking graphics in this category showed both varying time stages and correct chronology when showing a biological process. For example, graphics depicting a biological hypothesis or theory would have shown the stages taken by researchers to come to their conclusions not just the end product. Another example would be to show the varying stages of forest succession after clear cutting an old-growth forest. Exemplary graphics would have shown multiple stages in correct order while average ranked graphics would have simply shown before and after or may have shown images out of correct order. Graphics were ranked as weak in this category when they showed only one time stage and no chronology.

Dynamic Balance: High ranking graphics in this principle included features such as feedback loops and emphasized ecological equilibrium. An example of this is shown when describing predator prey interactions. A graphic only showing the color of an arctic hare changing to match the changing seasons without any indication of the reason for that change would have earned the ranking of average. An image that showed the changes in the fur color from season to season and also shows how this color change enhances background matching camouflage in the hares and thus protects them from their natural predators the arctic foxes would earn a ranking of exemplary in dynamic balance. An image that simply shows the changing fur color and with no linkages as response to seasonal changes or predation pressure would earn a ranking of weak.

The second rubric I created focused on my second research question (see Appendix D). This question, "How do select popular, collegiate introductory biology textbooks better utilize a mixture of reductionistic thinking and systems thinking through graphics?", took a more qualitative approach to the analysis of textbook graphics. Using a reflexive, ethnographic approach in creating this rubric, I left room for flexibility in the analysis. Four basic categories were created for the purpose of classifying graphics into groups, directly systems-based, indirectly systems-based, indirectly reductionist, and directly reductionist. Although graphics should be discernable into these separate groupings, these are not meant to be viewed as strictly rigid classifications. There is some degree of overlap between the rankings in this rubric.

This ethnographic, systems-based rubric used the five foundations of ecological literacy as described by the Center for Ecoloteracy (Center for Ecoliteracy, 2012). The first foundation of ecological literacy is empathy. A graphic that ranked as directly systems-based in this foundation overtly displayed human empathy for other life forms. Humans would have been shown as fully integrated within an ecosystem. Indirectly systems-based implied this empathy but not show it explicitly. Indirectly reductionistic might have suggested that humans are separate without directly displaying this reductionistic concept. Directly reductionistic made no attempt to show any empathy to other living things and clearly displayed humans as separate and above their ecosystem.

Rating graphics on the second foundation, visibility, a graphic was classified as directly systems-based if it drew light onto normally invisible practices. These types of graphics would show how human action can affect other communities, life forms and the biosphere. Indirectly systems-based graphics suggested or implied that some human practices can harbor hidden aspects that can adversely affect other living things or ecosystem cycles. Indirectly reductionist graphics did not show any invisible practices and may have suggested that visibility of how humans can affect other aspects of the biosphere as unimportant. Graphics that ranked as directly reductionist showed no aspects of any invisible practices of humans affecting their own ecosystem.

The third foundation of ecological literacy is the understanding of consequences. Graphics that were strong in this foundation would show what can happen from a human action before that action is taken. For example, not only showing human population grown in the form of a growth curve but also showing the effect that human growth may have the earth's remaining arable land. A graphic with a rating of indirectly systems-based only suggested possible consequences, but it may not show them explicitly through the graphic. An indirectly reductionist rating was applied to graphics that suggest linkages to other living things but without any consequences or effects of human actions. A directly reductionist rating was applied to a graphic that showed no linkages to other living organisms nor any effects of human actions on ecosystems.

Rating graphics on the foundation of processes would place graphics that show a complex understanding of the Earth's processes and the cycles present with ecosystems in the highest category of directly systems-based. Graphics rated as indirectly systems-based suggested cycles without showing them or showed incomplete cycles. Indirectly reductionist placed more emphasis on the independent parts instead of whole cycles within an ecosystem. Directly reductionist graphics did not show any systems or cycles and instead only displayed independent parts.

The last foundation of ecological literacy used in the rubric is sustainability. Graphics that were classifiable as directly systems-based showed the complexity and quality of the web of relationships within any living community. These graphics fostered cooperative thinking with people and other living things. Indirectly systems-based graphics suggested that the quality of this web can be changed or affected by human action. Indirectly reductionist graphics showed some interrelationships between humans and other parts of the ecosystem but still emphasized humans as independent from other living things. Graphics showing a directly reductionistic lens emphasized humans as independent and superior to other living things. These last graphic ratings do not encourage cooperative living between humans and other living things.

To address my third research question I created a third rubric based on Tufte's main principles of good graphics (see Appendix C). My third question asked, "How many sample collegiate introductory biology textbooks use reader-centered graphics that correspond to classic Tuftian principles?" In creating this last rubric I focused on examining graphics for alignment with Tufte's eight main principles; show the data, avoid distortion, maximize data ink, avoid chart junk, have a clear purpose, clarify large data sets, using multi-variate displays of data, and using data along with written descriptions. (Tufte, 1990, 1997, 2001, 2006). I scored each graphic based on specific adherence to each of these principles.

For a graphic to earn the highest ranking in Tuftian principles it must have first shown the data. By clearly showing the data, a graphic displayed the data with clarity and focus. Good graphics that earned the highest ranking in avoiding distortion accurately displayed the data while preventing misrepresentation by using the proper scale and including all data instead of selectively including only conforming data.

Graphics that followed the Tuftian principles of good graphics would have also earned high ranking on this rubric by maximizing data ink and avoiding chart junk. Graphics should not have included any unnecessary graphics or pictures that simply distract the reader from focusing on the data. According to Tufte good graphics use the least amount of data ink to convey the information accurately (Tufte, 1990, 1997, 2001, 2006). Likewise, elaborate drawings or unnecessary pictures create 'chart junk' and may only function to confuse the reader. Graphics that include and chart junk ranked lowest in this principle.

Good graphics also displayed a clear purpose that was obvious to the reader upon initial examination. Written descriptions can be used to help better explain a graphic and can work along with the data. Graphics earned high rankings on this rubric when the purpose was made obviously clear to the reader and when words were used within a graphic to further elaborate concepts.

Lastly, good graphics ranked highest in this Tuftian based rubric when they incorporated multi-variate displays of data and simplified large data sets. When displaying large amounts of data it becomes essential to present it in a fashion that clarifies the main point to the reader. Some data may even lend itself to multi-variate displays using statistical or descriptive methods to simplify and clarify unwieldy data. Graphics that ranked highest in these two principles simplified large data sets and incorporated multivariate displays when it was necessary to organize confusing data.

Figure 7 illustrates the framework for a systems-based analysis of biology textbook graphics. The context of this analysis is based in the essential elements of systems-based thinking which is the bedrock of ecological literacy. The competencies show how textbook authors recognize and attempt to incorporate some of these elements into their graphics. The outcomes are examples of how these concepts are actually demonstrated graphically in textbooks. The development of the systems-based rubric (Appendix B) with which to gauge the graphics was based largely on this framework.

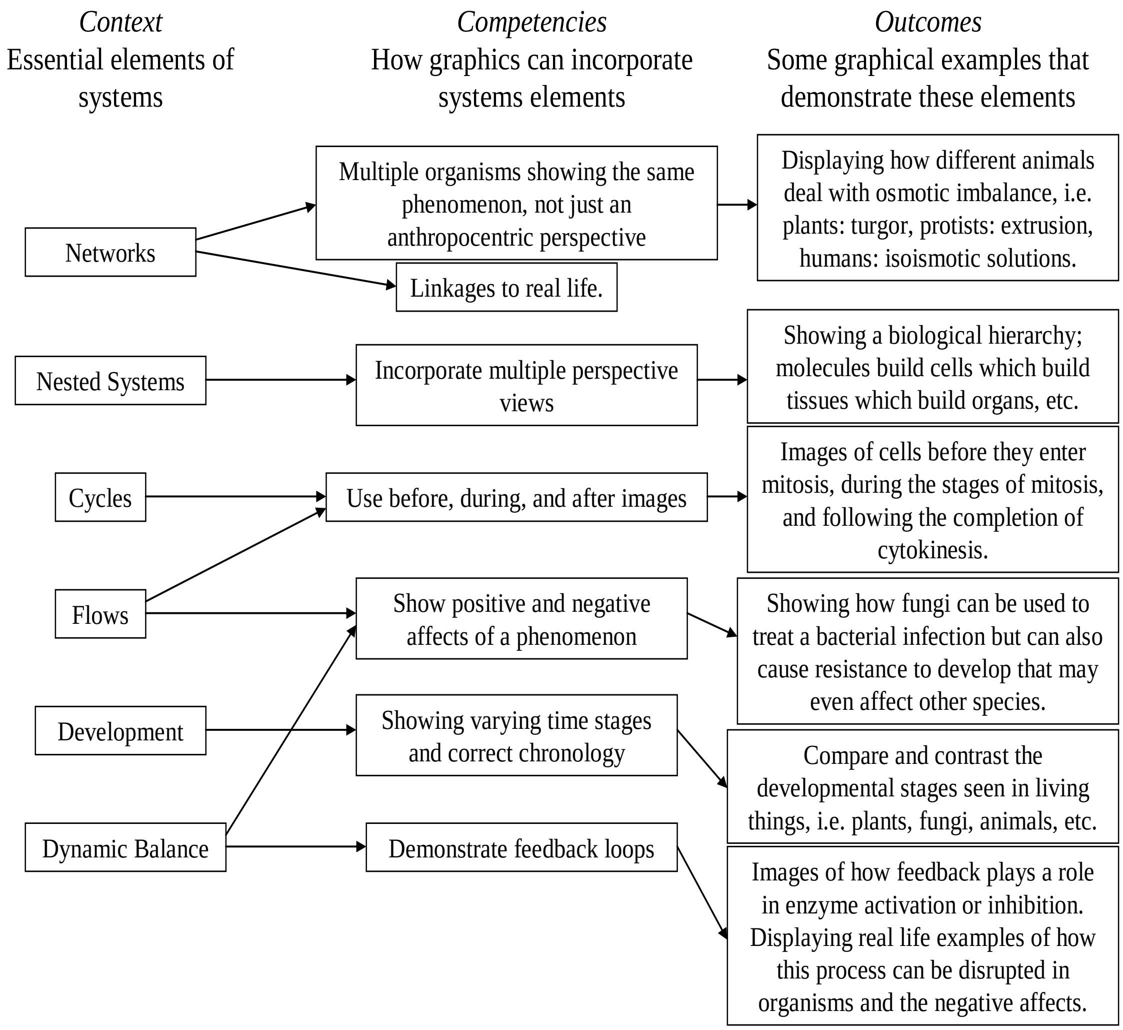

Figure 7. Framework for systems-based graphic analysis

Procedures

Figure 8 contains the timeline I created showing the steps I have taken in the development and progress of this research.

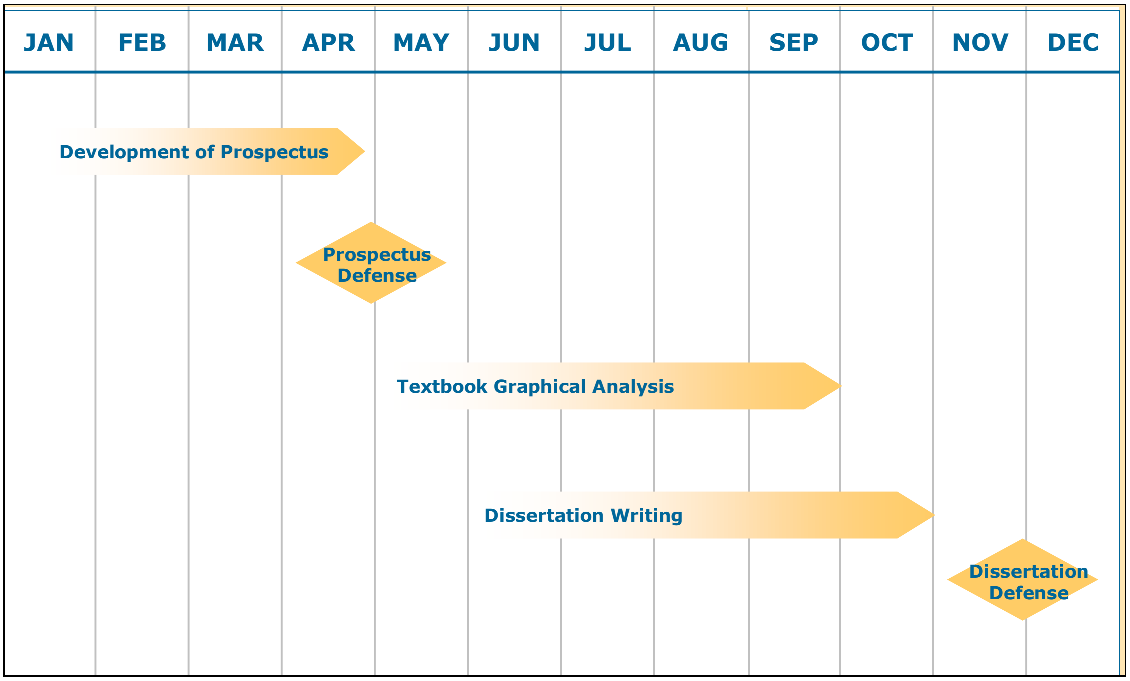

Figure 8. Systems-based graphic analysis of biology texts research timeline Jan 2013 - Dec 2013

Data Analysis

I analyzed all of the graphics in the selected textbook chapters including illustrations with and without captions, pictures with and without captions, and figures with and without captions. This also included any diagrams showing scientific processes and any supplementary graphics placed in margins. These methods followed those as identified by Chiappetta et al. (1991b/2004) for figures that should and should not be included in a content analysis of science textbooks. Chiappetta did recommend the exclusion of figures without captions for analysis but I have chose to include those figures also because I felt that they still had the potential to create an implicit sense of systems-thinking or reductionistic-thinking.

For this study, I incorporated QUAN→qual sequencing with slightly greater emphasis on the quanitatve portion of analysis. Using the created rubric I was able to quantify the degree of systems-thinking incorporated into the graphical representations of common biological processes. I also used basic descriptive statistics to summarize and represent the types of information presented in each graphic in selected chapters (Ivankova, Creswell, & Stick, 2006; Johnson & Christensen, 2008; Onwuegbuzie & Dickinson 2008). For the quantitative portion, I focused on descriptive and comparative statistical methods (Johnson & Christensen, 2008). These techniques were used to compare quantitative data collected from graphics when applying the aforementioned constructed rubrics.

In addition to scoring using the rubrics for the quantitative portion of this research, each graphic was also categorized on the basis of an implied or direct display of systems-based or reductionist thinking. I qualitatively examined the degree of content that uses a systems-based perspective in presenting information. Using an ethnographic style of content analysis as defined by Altheide (1996), I examined each selected graphic for explicit content, implicit content, and contextual expression, and overall impression. Each graphic was then classified as directly systems-based, indirectly systems-based, indirectly reductionist, directly reductionist or mixtures of these categories. This method of data analysis allowed for initial variables and categories but also encouraged flexibility and the possibility of emergence of new or additional categories based on ongoing analysis. The following list represents the order of data analysis:

- Score each of the graphics on the systems rubric in the selected chapters in each of the five sampled textbooks.
- Score each of the graphics on the ethnographic rubric in each of the selected chapters in each of the five sampled textbooks.
- Score each of the graphics on the Tuftian rubric in the selected chapters in each of the five sampled textbooks.
- Compile and compare data from each of these rubrics using descriptive statistics.

- Describe and discuss the data from each of these rubrics using an ethnographic style.

Developing a sense of interconnectedness seems to be important to creating long-lasting ecological consciousness. I believe that textbooks can and do influence how an instructor presents material and how students interpret that information. There still seems to be a tendency of textbook writers to use a more reductionist approach in an attempt to simplify information. At the same time, students may lose a sense of interconnectedness between, not only the topics with a general biology course but among all biology courses and even between other sciences and disciplines.

Possible Limitations of the Research

A potential limitation of this research may be the low sample size of analyzed textbooks. Although there are currently a very small variety of textbook that are used in general biology classes with any regularity, this sample may not represent all the possible permutations that are available to professors. Although I do believe that the quality of textbook graphics seems to be increasing, but there are still areas that demand improvement. Future research could incorporate a greater breadth of textbooks and possibly a wider variety of smaller, independent publishers. I also hope that by using qualitative methods mixed with quantitative methods bolstered the breadth of data and the overall internal validity. Another possible threat limitation could be limiting analysis to that of the textbook graphics. An author may imply systems-thinking into the writing of the text and not only through graphics. Through this research I elected not to focus on text and instead turn my attention solely on graphics. Future research could include an analysis of text in addition to graphics.

Reliability in content analysis is defined by Neuendorf as "the extent to which a measured procedure yields the same results on repeated trials" (2002, p. 141). In content analysis this concern is paramount to producing trustworthy results. In this same vein, validity can also be a concern when conducting content analysis. Validity and reliability are distinct from each other and although is necessary for validity it is not a sufficient condition (Neuendorf 2002). In order to maximize the level of intracoder reliability in this study I have used only one coder. Additionally, reanalyzing the same material after a period of time will be another means of establishing intracoder reliability. This allows for establishing a measure of stability by quantifying the degree of similarities between these codings separated by time. A high degree of intracoder reliability can help improve the overall reliability of a study.

Validity can also be a threat to any content analysis. Validity as defined by Neuendorf is "the extent to which a measuring procedure represents the intended, and only the intended concept" (2002, p. 112). Overall validity is asking if the research really measured what was intended to be measured.

Four primary measures were taken in order to establish validity for this study. First, in order to assure an accurate sample of textbooks, sales records were used to find some of the most frequently purchased textbooks in the U.S. Also, to be as inclusive as possible all of the graphics from each selected chapter included in this analysis. This allowed for data to be included in this analysis that represents every image in each of the selected chapters of these textbooks.

Second, the systems-based rubric utilized categories established by Capra (1996) and further modified by the Center for Ecoliteracy's core ecoliteracy concepts (2004). The levels created in this rubric were based upon these recognized categories and concepts. Analysis of the textbooks did not suggest any further modification of this rubric in order to best accurately assess the meaning of the graphics.

Third, the Tuftian-based rubric was created based on 'good graphics' parameters established by Tufte (1990, 1997, 2001, 2006). This rubric was constructed following Tufte's recommendation for the creation of effective scientific display of data and other information. Therefore graphics falling inside these recognized parameters were considered to efficiently and accurately represent data.

The final step in establishing validity for the purpose of this content analysis was to establish a set of flexible categories by which each analyzed graphic was classified. The method of analysis follows the techniques proposed by Altheide (1996) as part of an ethnographic style content analysis. These predetermined categories initially guided the qualitative part of this study but also allowed for development throughout the research of an objective of constant reflection and discovery when analyzing the graphics.

Summary

There is a growing need for science educators to answer the call for more socially and environmentally aware adults entering the workforce. The students we see now will be future leaders, workers, educators, parents and voters. To answer this call, we need agreement on what really constitutes ecological awareness and ultimately true ecological literacy. By incorporating a variety of ideas and theories garnered from my major areas of study, education and biology, I better illustrated the places that may need improvement especially when it comes to the development and use to educational materials such as textbooks. Development and critical analysis of what we choose to include or exclude in our curriculum and educational materials about how systems are a integral part of science will affect if and when we may bring about real development of true ecological literacy and ultimately ecologically conscientious action.

Chapter 4 Results of Textbook Graphical Analysis

Through this research I have developed a detailed means of assessing college textbook graphics for systems thinking and for the presence of ecologically-framed concepts. The primary goal of this research was to develop a better picture of how much textbooks can help advance ecological literacy in students. Through the creation of an appropriate method of content analysis for biology textbooks, researchers and scholars can better assess the incorporation of systems-based ideas into texts and lectures thus potentially improving the ecological literacy and ecologically conscientious action in college students.

I have conducted a detailed analysis of the graphical content of a cross selection of college level introductory biology textbook chapters. I have hypothesized that most graphics will fall somewhere along this continuum between two extreme approaches, systems-based and reductionist. As previously mentioned, since generally only a subset of biology majors ever receive any specific ecology training, and non-biology majors usually receive no ecology training at all, it becomes increasingly imperative to consider a more ecological and systems-based tone in all general biology textbooks.

Graphic analysis began with a focus on my first research question: what is a typical volume of graphic content within a sample of popular, collegiate, introductory, biology, textbooks that uses systems-based thinking? To address this question the Systems-based Rubric (SR) (Appendix B) was first used to analyze the two indicated chapters, the introductory and a specified chapter devoted to ecology in each of the selected textbooks (see Appendix A). I selected these two chapters because they are frequently considered essential topics in an introductory college biology course. I also desired to focus on chapters that were most likely to include a systems-based perspective. These are also chapters that are most likely to benefit from a greater degree of systems-based graphics.

Collegiate Introductory Biology Textbooks Using Systems-Based Graphics

My first step in the process was to conduct a systems-based graphic analysis in chapters 1 and 54 in the textbook *Biology* (Brooker et al. 2011). Chapter 1, An Introduction to Biology, was a general overview chapter focused on basic biology and Chapter 54, An Introduction to Ecology and Biomes, was another overview chapter centered on basic ecology. Using the SR as a quantitative analysis on each of these chapters yielded 21 graphics in Chapter 1 and 26 graphics in Chapter 54. This analysis revealed consistently low scores on the SR. The most commonly obtained graphic score on the SR was 9 out of possible 18 in Chapter 1 and then an 8 out of possible 18 in Chapter 54. This textbook averaged 9.3, out of a possible 18, for both chapters combined on the SR analysis. The large majority of the graphics used in both chapters of this textbook can therefore be classified primarily reductionistic when classified based on the results of the SR analysis. This quantitative analysis lead to the classification of the Brooker et al. *Biology* textbook (2011) as generally reductionistic in presentation. Table 4 illustrates the results of this systems-based graphic analysis of Chapters 1 and 54 in the textbook *Biology 2nd ed.* (Brooker et al. 2011).

The next step in this process was to conduct a systems-based graphic analysis in Chapters 1 and 37 in the textbook *Campbell Biology: Concepts & Connections* (Reece et al. 2012). Chapter 1, Biology: Exploring Life, is an introduction to some of the fundamentals of biology and Chapter 37, Communities and Ecosystems, emphasizes community ecology. The SR was again employed for the analysis on each of these chapters. Chapter 1 presented 18 graphics, while Chapter 54 included 34 graphics. Again this analysis also revealed fairly low scores

Table 4. Results of SR analysis of *Biology* by Brooker et al. (2011)

Brooker Ch 1	Score	Brooker Ch 54	Score
Front Graphic	7	Front Graphic	8
Fig. 1.1	9	Fig. 54.1	7
Fig. 1.2	9	Fig. 54.2	11
Fig. 1.3	9	Fig. 54.3	13
Fig. 1.4	9	Fig. 54.4	14
Fig. 1.5	10	Fig. 54.5	13
Fig. 1.6	11	Fig. 54.6	10
Fig. 1.7	8	Fig. 54.7	8
Fig. 1.8	10	Fig. 54.8	8
Fig. 1.9	10	Fig. 54.9	8
Fig. 1.10	9	Fig. 54.10	8
Fig. 1.11	10	Fig. 54.11	10
Fig. 1.12	10	Fig. 54.12	10
Fig. 1.13	12	Fig. 54.13	9
Fig. 1.14	12	Fig. 54.14	11
Fig. 1.15	9	Fig. 54.15	8
Fig. 1.16	7	Fig. 54.16	8
Fig. 1.17	7	Fig. 54.17	12
Fig. 1.18	11	Fig. 54.18	7
Fig. 1.19	10	Fig. 54.19	6
Fig. 1.20	6	Fig. 54.20	6
		Fig. 54.21	12
		Fig. 54.22	8
		Fig. 54.23	7
		Fig. 54.24	9
		Fig. 54.25	6

consistently earned on the SR. The most commonly obtained graphic score on the SR was a 7 out of possible 18 in Chapter 1 and then an 8 out of possible 18 in Chapter 54. This textbook averaged a 9.5, out of a possible 18, for both chapters combined on the SR analysis. In this textbook, as was seen in the previously examined textbook, the large majority of the graphics used in both chapters were classified as primarily reductionistic when using the SR analysis. This quantitative analysis has lead to the classification of *Campbell Biology: Concepts & Connections* (Reece et al. 2012) as generally reductionistic nature. Table 5 presents the results of this systems-based graphic analysis of Chapters 1 and 37 in the textbook *Campbell Biology: Concepts & Connections* (Reece et al. 2012).

Table 5. Results of SR analysis of *Campbell Biology* by Reece et al. (2012)

Reece Ch 1	**Score**	**Reece Ch 37**	**Score**
Front Graphic	7	Front Graphic	9
Fig. 1.1	12	Fig. 37.3A	7
Fig. 1.2	10	Fig. 37.3B	7
Fig. 1.3	7	Fig. 37.4	8
Fig. 1.4	14	Fig. 37.5A	8
Fig. 1.5	6	Fig. 37.5B	8
Fig. 1.6	10	Fig. 37.6	15
Fig. 1.7A	7	Fig. 37.7	9
Fig. 1.7B	6	Fig. 37.8	11
Fig. 1.7C	14	Fig. 37.9	11
Fig. 1.7D	9	Fig. 37.10A	8
Fig. 1.8	7	Fig. 37.10B	8
Fig. 1.9A	12	Fig. 37.11A	9
Fig. 1.9B	7	Fig. 37.11B	8
Fig. 1.9C	7	Fig. 37.11C	8
Fig. 1.9D	9	Fig. 37.11D	8
Fig. 1.9E	9	Fig. 37.12A	7
Fig. 1.10	8	Fig. 37.12B	12
		Fig. 37.13A	9
		Fig. 37.13B	8
		Fig. 37.13C	7
		Fig. 37.14	14
		Fig. 37.15	8
		Fig. 37.16A	9
		Fig. 37.16B	12
		Fig. 37.17	14
		Fig. 37.18	9
		Fig. 37.19	13
		Fig. 37.20	14
		Fig. 37.21	14
		Fig. 37.22A	10
		Fig. 37.22B	12
		Fig. 37.23A	8
		Fig. 37.23B	8

I then conducted the quantitative systems-based graphic analysis of Chapters 1 and 57 in the textbook *Biology* (Raven et al. 2011). The two chapters I selected for analysis were Chapter

1, The Science of Biology, which is an introductory chapter intended to orient the reader on basic biology and Chapter 57, Community Ecology, which deals with community ecology. I again used the SR for the analysis of each of these chapters. Chapter 1 displayed 14 graphics, which was the lowest number of graphics used in any of the first chapters analyzed. Chapter 57 included a larger number of graphics at 27. Even though this analysis uncovered still somewhat low scores on the SR, Chapter 57 did have the highest overall average score of 10.9 out of a possible 18. The most commonly obtained graphic score in Chapter 1 on the SR was a 10 out of 18 while Chapter 57 earned an 8 out of 18 most frequently. This textbook averaged an overall 10.4, out of a possible 18, for both chapters combined on the SR analysis, which was the highest score of any of the textbooks. Even though this was the highest score out of all five textbooks examined, a 10.4 is still considerably lower than the 18 that was possible on this rubric. Furthermore, this analysis indicated that the graphics used in both chapters can therefore be classified as primarily reductionistic when categorized based on the SR analysis. This quantitative analysis has lead to the classification of *Biology* (Raven et al. 2011) as generally reductionistic. Table 6 presents the results of this systems-based graphic analysis of Chapters 1 and 57 in the textbook *Biology* (Raven et al. 2011).

I conducted the systems-based graphic analysis of Chapters 1 and 27 in the textbook *Biology: Life on Earth* (Audesirk et al. 2011). I selected Chapter 1, An Introduction to Life on Earth, and Chapter 27, Community Interactions, for analysis with the SR. The focus of Chapter 1 is on basic biology background and foundations, while Chapter 27 introduces basics of community -based ecology. Chapter 1's most commonly earned graphical score was a 10 out of 18. Alternately, Chapter 27's most commonly earned score was a 9 out of a possible 18. This textbook averaged overall a 9.8, out of a possible 18, for both chapters combined on the SR

Table 6. Results of SR analysis of *Biology* by Raven et al. (2011)

Raven Ch 1	**Score**	**Raven Ch 57**	**Score**
Front Graphic	6	Front Graphic	7
Fig. 1.1	10	Fig. 57.1	8
Fig. 1.2	7	Fig. 57.2	12
Fig. 1.3	10	Fig. 57.3	12
Fig. 1.4	11	Fig. 57.4	11
Fig. 1.5	6	Fig. 57.5	13
Fig. 1.6	7	Fig. 57.6	11
Fig. 1.7	8	Fig. 57.7	10
Fig. 1.8	8	Fig. 57.8	15
Fig. 1.9	8	Fig. 57.9	15
Fig. 1.10	11	Fig. 57.10	11
Fig. 1.11	9	Fig. 57.11	13
Fig. 1.12	10	Fig. 57.12	8
Fig. 1.13	10	Fig. 57.13	8
		Fig. 57.14	8
		Fig. 57.15	10
		Fig. 57.16	9
		Fig. 57.17	9
		Fig. 57.18	9
		Fig. 57.19	9
		Fig. 57.20	13
		Fig. 57.21	14
		Fig. 57.22	14
		Fig. 57.23	10
		Fig. 57.24	14
		Fig. 57.25	12
		Fig. 57.26	10

analysis, which was the second highest overall score. As was mentioned about the previous textbook, an overall score of 9.8 is still considerably lower than the 18 that was possible on this rubric. Again, this analysis indicated that the graphics used in both chapters can therefore be classified as primarily reductionistic when categorized based on the results of the SR analysis. This analysis has lead to the classification of *Biology: Life on Earth* (Audesirk et al. 2011) as primarily reductionistic. Table 7 confirms the results of the systems-based graphic analysis of Chapters 1 and 27 in this textbook.

Table 7. Results of SR analysis of *Biology: Life on Earth with Physiology* by Audesirk et al. (2011)

Audesirk Ch 1	**Score**	**Audesirk Ch 27**	**Score**
Front graphic	10	Front Graphic	8
Fig. 1-1	10	Fig. 27-1	12
Fig. 1-2	6	Fig. 27-2	8
Fig. 1-3	6	Fig. 27-3	10
Fig. 1-4	10	Fig. 27-4	9
Fig. E1-1	12	Fig. 27-5	9
Fig. E1-2	13	Fig. 27-6	9
Fig. 1-5	9	Fig. 27-7	8
Fig. 1-6	6	Fig. 27-8	9
Fig. 1-7	7	Fig. 27-9	9
Fig. 1-8	7	Fig. 27-10	9
Fig. E1-3	12	Fig. 27-11	9
Fig. 1-9	6	Fig. E27-1	10
Fig. 1-10	12	Fig. 27-12	9
Fig. 1-11	11	Fig. E27-2	9
Fig. E1-4	10	Fig. 27-13	9
Fig. 1-12	7	Fig. 27-14	8
		Fig. 27-15	13
		Fig. 27-16	16
		Fig. 27-17	16
		Fig. 27-18	12
		Fig. 27-19	8

This was the lowest mode average obtained out of all five of the textbooks when examining Chapter 1. Since the lowest possible score on the SR is a five, obtaining a six on this measure is indicative of a strongly reductionistic style used throughout this chapter. Chapter 15 did not score much better with an overall average of 7 out of a possible 18. This textbook also averaged a 8.4, out of a possible 18, for both chapters combined on the SR analysis, which was also the lowest overall score. This analysis suggests that *What is Life?* (Phelan 2010) is therefore classifiable as strongly reductionistic in style and presentation of its graphics. Table 8 confirms the results of the systems-based graphic analysis of Chapters 1 and 15 in this textbook.

Table 8. Results of SR analysis of *What is Life* by Phelan (2010)

Phelan Ch 1	**Score**	**Phelan Ch 15**	**Score**
Front Graphic	8	Front Graphic	8
No Fig. Num.	6	No Fig. Num.	7
Fig. 1-1	6	Fig. 15-1	7
Fig. 1-2	6	Fig. 15-2	9
Fig. 1-3	7	Fig. 15-3	9
Fig. 1-4	6	Fig. 15-4	9
No Fig. Num.	7	No Fig. Num.	6
Fig. 1-5	10	Fig. 15-5	8
No Fig. Num.	6	Fig. 15-6	8
Fig. 1-6	6	Fig. 15-7	9
Fig. 1-7	7	No Fig. Num.	7
Fig. 1-8	6	Fig. 15-8	9
Fig. 1-9	7	Fig. 15-9	10
Fig. 1-10	10	Fig. 15-10	6
Fig. 1-11	6	Fig. 15-11	10
Fig 1-12	11	No Fig. Num.	7
No Fig. Num.	6	Fig. 15-12	12
Fig. 1-13	12	Fig. 15-13	11
Fig. 1-14	7	Fig. 15-14	12
Fig. 1-15	10	Fig. 15-15	6
Fig. 1-16	6	Fig. 15-16	14
No Fig. Num.	6	Fig. 15-17	14
Fig. 1-17	6	Fig. 15-18	14
Fig. 1-18	8	Fig. 15-19	11
Fig. 1-19	6	No Fig. Num.	6
Fig. 1-20	6	No Fig. Num.	7
No Fig. Num.	6	Fig. 15-20	9
No Fig. Num.	8	Fig. 15-21	8
		Fig. 15-22	12
		Fig. 15-23	13
		Fig. 15-24	8
		Fig. 15-25	8
		Fig. 15-26	7
		Fig. 15-27	9
		Fig. 15-28	7
		Fig. 15-29	8
		No Fig. Num.	7
		Fig. 15-30	11
		Fig. 15-31	14

The final textbook analysis conducted using the SR examined then textbook *What is Life?* (Phelan 2010). I analyzed Chapter 1, Scientific Thinking, and Chapter 15, Ecosystems and Communities from this textbook with the SR. Chapter 1 in this textbook presented information consistent with a basic introduction to the biological sciences, while Chapter 15 shifted emphasis to community and ecosystem ecology. The most frequently earned score in Chapter 1 for this textbook was a 6 out of a possible 18.

Finally, I generated an analysis of all chapters, in all five books. A descriptive summary of all of the data generated through specific chapter analyses is included in Table 9. Table 9 is a presentation of the data for all five textbooks for both chapters that were analyzed. Again, the focus of each text's first chapter was introductory while the second chapter focused on ecology. The Phelan textbook showed the highest amount of graphics in both chapters. These values far surpassed the number of graphics in any of the other textbooks examined. Even with the high number of graphics included in this textbook it still scored the lowest in Chapter 1 for system-based qualities and scored poorly overall in system-based graphical features. Raven *Biology* scored the highest overall for system-based graphics.

Table 9. Summary of the results of SR analysis. The highest value in each category row is in boldface. Lowest value in each category row is in italics.

Highest possible = 18	**Brooker et al.**		**Reece et al.**		**Raven et al.**		**Audesirk et al.**		**Phelan**	
Chapter	Ch 1	Ch 54	Ch 1	Ch 37	Ch 1	Ch 57	Ch 1	Ch 27	Ch 1	Ch 15
No. Graphics	21	26	18	34	*14*	27	17	22	28	**40**
Mean	9.3	9.1	8.9	9.7	8.6	**10.9**	9.1	10.0	*7.2*	9.3
Mode	9	8	7	8	**10**	8	**10**	9	*6*	7
Overall Mean	9.3		9.5		**10.4**		9.8		*8.4*	

Figures 9 and 10 present a graphic representation of the SR data. All of the graphics within each chapter of each textbook are shown as a single bar. Figure 9 shows the data from

Chapter 1 for each of the textbooks. Figure 10 shows all of the data for the ecology chapter for each of the textbooks. The different colors represent the compiled scores for each graphic. In order to improve the clarity of this bar graph, rubric scores where condensed into four groups. Graphics receiving scores between six and eight were grouped into the lowest category and are shown in the lightest grey in each bar. Graphics receiving scores between nine and eleven were grouped into the low/moderate category and are indicated by a darker grey in each bar. Graphics earning scores between twelve and fourteen were grouped into the moderate/high category and are displayed in moderately dark grey within each bar. Graphics earning the highest scores between fifteen and nineteen were classified with a ranking of high and are shown in the darkest shade of grey within each bar.

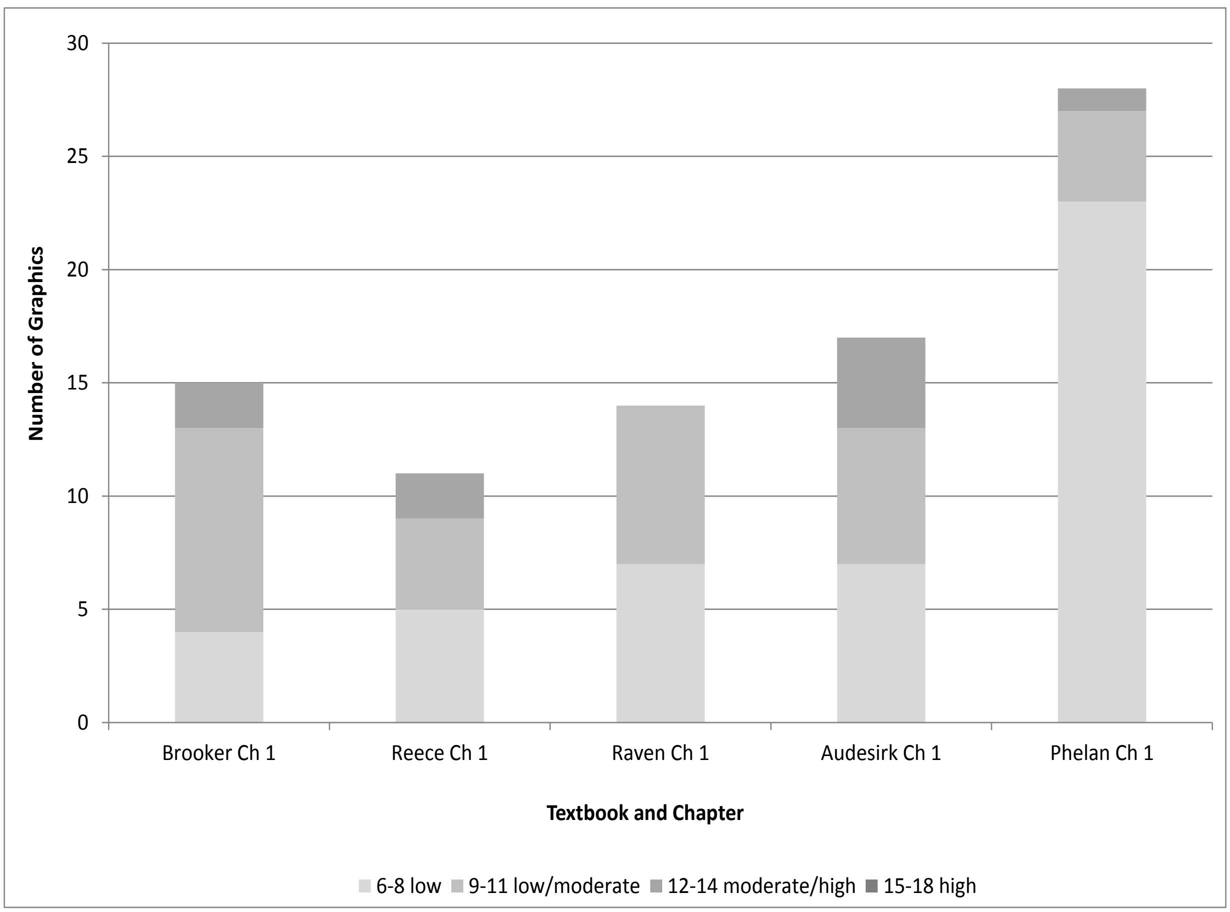

Figure 9. Summary of SR data for introductory chapter.

Note in Figure 9 that none of the textbooks earned the high ranking on any graphics in Chapter 1 for the SR. Additionally, the Raven textbook did not earn any ranking above the low/moderate level for any of the graphics in Chapter 1. In all five of the textbooks analyzed, the majority of graphics were classified as low or low/moderate.

Because the second chapter analyzed for each textbook was selected specifically for its attention on ecology as a primary topic, I expected higher scores in general. While this was true to a small degree with Figure 10 showing three textbooks that did have a small number of graphics that earned the high level ranking, Reece's *Biology* (2012), Raven's *Biology* (2011),

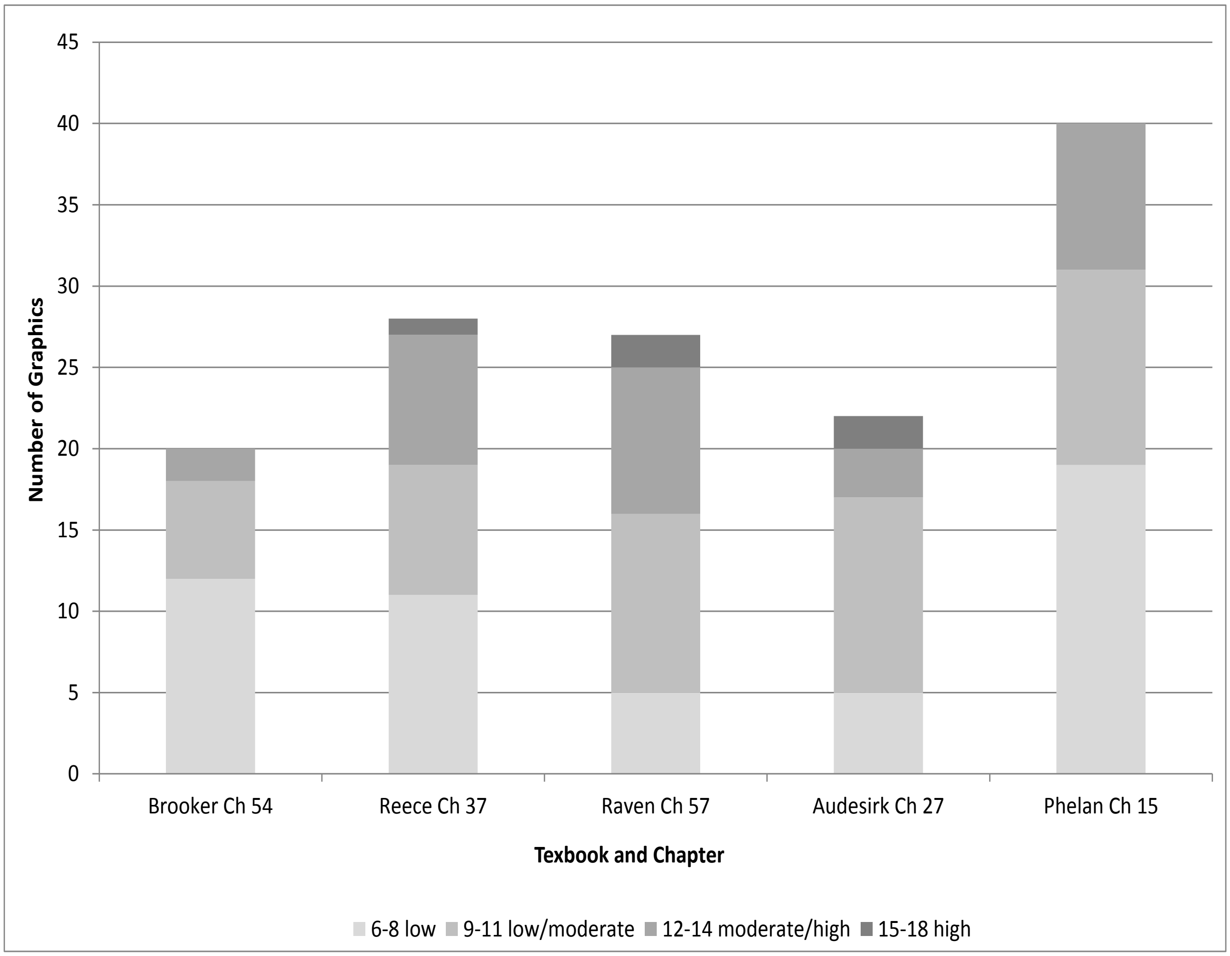

Figure 10. Summary of SR data for ecology chapter.

Audesirk's *Biology* (2011), there were still two textbooks that did not have any graphics that showed this high level ranking for system-based features, Booker's *Biology* (2011) and Phelan's *What is Life* (2010). Three textbooks showed the largest number of graphics ranking only at the lowest level, Brooker's *Biology* (2011), Reece's *Biology* (2012), and Phelan's *What is Life* (2010). While two textbooks had their largest group of graphics ranking in the low/moderate range, Raven's *Biology* (2011) and Audesirk's *Biology* (2011).

Collegiate Introductory Biology Textbooks Using Reader-Centered Graphics that Correspond to Classic Tuftian Principles

Graphic analysis continued with a shift in focus to my third research question: how many sample collegiate introductory biology textbooks use reader-centered graphics that correspond to classic Tuftian principles? To address this question the Tuftian Rubric (TR) (see Appendix C) was used to analyze the two indicated chapters in each of the selected textbooks. Table 10 presents the results of the TR analysis of Chapters 1 and 54 in the textbook *Biology* (Brooker et al. 2011).

As can be seen in Table 10, the data obtained from the TR for *Biology* (Brooker et al. 2011) were fairly consistent throughout both chapters. The most frequently earned score on the TR for graphics without numeric data was a 9 out of a possible 10 for Chapter 1 and a 10 out of a possible 10 for Chapter 54. Overall this textbook scored an average of 9.5 out of a possible 10 on the TR without numeric data for both chapters combined. For the graphics that did include numeric data the overall average was a 15.8 out of a possible 18 for both chapters combined on the TR. Based on this analysis *Biology* by Brooker et al. (2011) is classifiable as moderate to highly Tuftian in its graphical components.

Table 10. Results of TR analysis of *Biology* by Brooker et al. (2011)

Brooker Ch 1	**Score**	**Brooker Ch 54**	**Score**
Front Graphic	9	Front Graphic	9
Fig. 1.1	9	Fig. 54.1	10
Fig. 1.2	9	Fig. 54.2	17
Fig. 1.3	9	Fig. 54.3	10
Fig. 1.4	10	Fig. 54.4	15
Fig. 1.5	9	Fig. 54.5	9
Fig. 1.6	9	Fig. 54.6	10
Fig. 1.7	17	Fig. 54.7	9
Fig. 1.8	8	Fig. 54.8	10
Fig. 1.9	13	Fig. 54.9	10
Fig. 1.10	10	Fig. 54.10	9
Fig. 1.11	18	Fig. 54.11	10
Fig. 1.12	9	Fig. 54.12	10
Fig. 1.13	9	Fig. 54.13	15
Fig. 1.14	9	Fig. 54.14	10
Fig. 1.15	17	Fig. 54.15	10
Fig. 1.16	7	Fig. 54.16	10
Fig. 1.17	8	Fig. 54.17	9
Fig. 1.18	9	Fig. 54.18	14
Fig. 1.19	10	Fig. 54.19	10
Fig. 1.20	10	Fig. 54.20	10
		Fig. 54.21	10
		Fig. 54.22	10
		Fig. 54.23	10
		Fig. 54.24	10
		Fig. 54.25	10

Table 11 presents the data obtained from the TR for *Campbell Biology* by Reece et al. (2012). These data were highly consistent throughout both chapters. The most frequently earned score on the TR for graphics without numeric data was a 10 out of a possible 10 for Chapter 1 and for Chapter 37. This textbook revealed an overall average of 9.7 out of a possible 10 for both chapters combined on graphics that did not include any numeric data. For the graphics that did include numeric data the overall average was a 17.5 out of a possible 18 for both chapters combined on the TR. This analysis of the TR for *Campbell Biology* by Reece et al. (2012) lead to the classification of this textbook as highly Tuftian in its graphical components. Table 11 is a compilation of the results of the TR analysis of Chapters 1 and 37 in the textbook *Campbell Biology: Concepts & Connections* (Reece et al. 2012).

Table 11**.** Results of TR analysis of *Campbell Biology* by Reece et al. (2012)

Reece Ch 1	**Score**	**Reece Ch 37**	**Score**
Front Graphic	10	Front Graphic	10
Fig. 1.1	10	Fig. 37.3A	9
Fig. 1.2	9	Fig. 37.3B	9
Fig. 1.3	10	Fig. 37.4	9
Fig. 1.4	9	Fig. 37.5A	10
Fig. 1.5	9	Fig. 37.5B	10
Fig. 1.6	9	Fig. 37.6	10
Fig. 1.7A	10	Fig. 37.7	10
Fig. 1.7B	10	Fig. 37.8	10
Fig. 1.7C	10	Fig. 37.9	10
Fig. 1.7D	10	Fig. 37.10A	10
Fig. 1.8	10	Fig. 37.10B	10
Fig. 1.9A	10	Fig. 37.11A	8
Fig. 1.9B	10	Fig. 37.11B	10
Fig. 1.9C	10	Fig. 37.11C	10
Fig. 1.9D	10	Fig. 37.11D	9
Fig. 1.9E	10	Fig. 37.12A	10
Fig. 1.10	10	Fig. 37.12B	9
		Fig. 37.13A	10
		Fig. 37.13B	10
		Fig. 37.13C	10
		Fig. 37.14	9
		Fig. 37.15	17
		Fig. 37.16A	10
		Fig. 37.16B	9
		Fig. 37.17	10
		Fig. 37.18	9
		Fig. 37.19	9
		Fig. 37.20	18
		Fig. 37.21	10
		Fig. 37.22A	10
		Fig. 37.22B	10
		Fig. 37.23A	10
		Fig. 37.23B	10

Table 12 displays the results of the TR analysis of Chapters 1 and 57 gathered for the textbook *Biology* by Raven et al. (2011). The data resulting from this analysis were again highly consistent throughout both of the chapters examined. The most commonly observed score on the TR for graphics without numeric data was a 10 out of a possible 10 for Chapter 1 and for Chapter 57. An overall score of 9.8 out of a possible 10 was obtained as an average on the TR for both chapters combined for graphics without any numeric data. This textbook revealed the

Table 12. Results of TR analysis of *Biology 9th ed.* by Raven et al. (2011)

Raven Ch 1	**Score**	**Raven Ch 57**	**Score**
Front Graphic	10	Front Graphic	10
Fig. 1.1	9	Fig. 57.1	10
Fig. 1.2	9	Fig. 57.2	13
Fig. 1.3	10	Fig. 57.3	15
Fig. 1.4	9	Fig. 57.4	10
Fig. 1.5	10	Fig. 57.5	18
Fig. 1.6	10	Fig. 57.6	10
Fig. 1.7	10	Fig. 57.7	17
Fig. 1.8	17	Fig. 57.8	18
Fig. 1.9	10	Fig. 57.9	17
Fig. 1.10	15	Fig. 57.10	10
Fig. 1.11	10	Fig. 57.11	10
Fig. 1.12	9	Fig. 57.12	10
Fig. 1.13	7	Fig. 57.13	10
		Fig. 57.14	10
		Fig. 57.15	10
		Fig. 57.16	10
		Fig. 57.17	10
		Fig. 57.18	10
		Fig. 57.19	10
		Fig. 57.20	10
		Fig. 57.21	10
		Fig. 57.22	16
		Fig. 57.23	10
		Fig. 57.24	15
		Fig. 57.25	10
		Fig. 57.26	10

second highest overall average on the TR when including only graphics without numeric data. Examination of the graphics that did include numeric data showed an overall average was a 16.1 out of a possible 18 for both chapters combined on the TR. This analysis of the TR for *Biology* by Raven et al. (2011) lead to the classification of this textbook as highly Tuftian in its graphical elements.

The textbook *Biology: Life on Earth with Physiology* by Audesirk et al. (2011) was then analyzed using the TR. The results of this analysis are presented in Table 13. These data were also very consistent throughout the two chapters. A 10 out of a possible 10 was the most commonly earned score on the TR for graphics without numeric data for both Chapters 1 and 27.

Table 13. Results of TR analysis of *Biology: Life on Earth with Physiology* by Audesirk et al. (2011)

Audesirk Ch 1	Score	Audesirk Ch 27	Score
Front graphic	10	Front Graphic	9
Fig. 1-1	9	Fig. 27-1	18
Fig. 1-2	9	Fig. 27-2	10
Fig. 1-3	6	Fig. 27-3	10
Fig. 1-4	10	Fig. 27-4	10
Fig. E1-1	10	Fig. 27-5	10
Fig. E1-2	10	Fig. 27-6	10
Fig. 1-5	10	Fig. 27-7	10
Fig. 1-6	9	Fig. 27-8	10
Fig. 1-7	10	Fig. 27-9	10
Fig. 1-8	10	Fig. 27-10	10
Fig. E1-3	10	Fig. 27-11	10
Fig. 1-9	10	Fig. E27-1	10
Fig. 1-10	10	Fig. 27-12	10
Fig. 1-11	15	Fig. E27-2	10
Fig. E1-4	10	Fig. 27-13	10
Fig. 1-12	8	Fig. 27-14	10
		Fig. 27-15	10
		Fig. 27-16	10
		Fig. 27-17	10
		Fig. 27-18	10
		Fig. 27-19	10

An overall average score of 9.9 out of a possible 10 was earned for both chapters combined for graphics without numeric data. An average of 9.4 out of a possible 10 was scored for Chapter 1, and an average of 10 out of a possible 10 was scored for Chapter 27. An overall score of 16.5 out of a possible 18 was obtained as an average on the TR for both chapters combined for graphics that included numeric data. This analysis of *Life on Earth with Physiology* by Audesirk (2011) lead to the classification of this textbook as highly Tuftian in its graphical elements. Table 13 displays the results of the TR analysis of chapters 1 and 27 in this textbook.

Lastly the textbook *What is Life?* by Phelan (2010) was analyzed using the TR. Table 14 conveys the results of this analysis. In same vein as the other textbooks analyzed, the Phelan textbook analysis revealed consistent results throughout the two chapters. The most frequently occurring score on the TR was a 10 out of a possible 10 for graphics without numeric data for both chapters 1 and 15. An overall average score of 9.6 out of a possible 10 on the TR was obtained for both chapters combined. An overall score of 18 out of a possible 18 was obtained as an average on the TR for both chapters combined for graphics that included numeric data. This result is not generalizable to the rest on the textbook because it is based upon a single graphic that appeared in Chapter 39 that actually included any numeric data.   This analysis of *What is Life* (Phelan 2010) has lead to the classification of this textbook as highly Tuftian in its graphical elements. This result is consistent with all four of the other textbooks included in this analysis.

Finally, I aggregated all data to compare results across texts and across each text's ecology-based chapter. A descriptive summary of the all of the data is shown in Tables 15 and 16. Tables 15 and 16 represent a descriptive summary for the TR analysis of the data for all five textbooks for both selected chapters. Upon examination of the graphics for adherence to specific Tuftian guidelines for good graphics it became apparent that the large majority of graphics did not include any numeric data. Because of this, graphics were ranked using a slightly modified scale depending on whether or not they included numeric data. The last four categories in the TR, clarify large data sets, use multi-variate displays of data to organize large data sets, use data

Table 14. Results of TR analysis of *Biology* by Phelan (2010)

Phelan Ch 1	Score	Phelan Ch 15	Score
Front Graphic	10	Front Graphic	10
No Fig. Num.	9	No Fig. Num.	9
Fig. 1-1	10	Fig. 15-1	10
Fig. 1-2	10	Fig. 15-2	10
Fig. 1-3	9	Fig. 15-3	10
Fig. 1-4	8	Fig. 15-4	10
No Fig. Num.	9	No Fig. Num.	10
Fig. 1-5	10	Fig. 15-5	10
No Fig. Num.	9	Fig. 15-6	10
Fig. 1-6	10	Fig. 15-7	10
Fig. 1-7	10	No Fig. Num.	8
Fig. 1-8	7	Fig. 15-8	10
Fig. 1-9	9	Fig. 15-9	6
Fig. 1-10	10	Fig. 15-10	10
Fig. 1-11	9	Fig. 15-11	10
Fig 1-12	10	No Fig. Num.	9
No Fig. Num.	9	Fig. 15-12	9
Fig. 1-13	10	Fig. 15-13	10
Fig. 1-14	10	Fig. 15-14	18
Fig. 1-15	10	Fig. 15-15	10
Fig. 1-16	10	Fig. 15-16	9
No Fig. Num.	10	Fig. 15-17	9
Fig. 1-17	15	Fig. 15-18	9
Fig. 1-18	15	Fig. 15-19	10
Fig. 1-19	9	No Fig. Num.	9
Fig. 1-20	9	No Fig. Num.	10
No Fig. Num.	9	Fig. 15-20	10
No Fig. Num.	8	Fig. 15-21	10
		Fig. 15-22	10
		Fig. 15-23	10
		Fig. 15-24	10
		Fig. 15-25	10
		Fig. 15-26	10
		Fig. 15-27	9
		Fig. 15-28	10
		Fig. 15-29	10
		No Fig. Num.	10
		Fig. 15-30	10
		Fig. 15-31	10

along with written descriptions, and reveal the data in layers and create depth, were excluded when analyzing any graphics without data. Thus the highest possible value for graphics without data was ten and the highest possible value for graphics with data was eighteen. Table 15 is a representation of the data for graphics that did not include numeric data. Table 16 shows the data from the remaining graphics that did show numeric data.

In Table 15 the Phelan textbook (2010) still indicated the highest amount of graphics in both chapters. Over all five of the textbooks their mean and median values were very similar. Most of the graphics examined earned scores of nine or ten, with the highest average coming from the Audesirk textbook (2011) and the lowest average coming from the Brooker textbook (2011). Although these numbers did indicate subtle trends, the slight numeric differences between the textbooks did not suggest a significant difference among the Tuftian quality of the textbook graphics.

Table 15. Summary of the results of the TR analysis, includes graphics without numeric data. The highest value in each category row is boldfaced. The lowest value in each category row is italicized.

Highest possible score = 10	**Brooker et al.**		**Reece et al.**		**Raven et al.**		**Audesirk et al.**		**Phelan**	
Chapter	Ch 1	Ch 54	Ch 1	Ch 37	Ch 1	Ch 57	Ch 1	Ch 27	Ch 1	Ch 15
No. Graphics	17	22	18	32	*12*	19	16	21	28	**39**
Mean	*9.0*	9.8	9.8	9.7	9.4	**10.0**	9.4	**10.0**	9.8	9.6
Mode	*9*	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**
Overall Mean	*9.5*		9.7		9.8		**9.9**		9.6	

Table 16 revealed similar results as Table 15. Most of the graphics analyzed scored fairly high in degree of adherence to Tuftian good graphics principles. This is apparent when examining the textbooks overall average scores ranging from 15.8 to 18. Since there were very few graphics in each textbook that used numeric data, the sample size for this analysis was also very limited. Some textbook chapters did not show any graphical representation of numeric data at all.

Table 16. Summary of the results of the TR analysis, includes graphics with numeric data. The highest value in each category row is in boldface. The lowest value in each category row is in italics

Highest possible score = 18	**Brooker et al.**		**Reece et al.**		**Raven et al.**		**Audesirk et al.**		**Phelan**	
Chapter	Ch 1	Ch 54	Ch 1	Ch 37	Ch 1	Ch 57	Ch 1	Ch 27	Ch 1	Ch 15
No. Graphics	4	4	*0*	2	2	**8**	1	1	*0*	1
Overall mean	*15.8*		17.5		16.1		16.5		**18**	

Ethnographic Analysis of Collegiate Introductory Biology Textbooks Using Systems-Based Graphics

The last part of my textbook analysis addressed my second research question: How do select popular, collegiate introductory biology textbooks better utilize a mixture of reductionist thinking and systems thinking through graphics? To guide my ethnographic analysis of the textbook graphics for systems-based qualities I used the third rubric that I developed, the Ethnographic Systems-based Rubric (ESR) (see Appendix D). I used the ESR to analyze the two indicated chapters in each of the selected textbooks.

Table 17 displays the results of the ESR graphic analysis of chapters 1 and 54 in the textbook *Biology 2nd ed.* (Brooker et al. 2011). This text averages a 9.7, out of a possible 20, for both chapters combined on the ESR analysis. Based on these data, the large majority of the graphics used in both chapters of this textbook were then classified as either directly reductionistic or indirectly reductionistic with only 4.8% in Chapter 1 and 34.6% in Chapter 54 classified as either indirectly systems-based or directly systems-based. Because the majority of the graphics analyzed from this textbook were not classified as either directly or indirectly systems-based, this book is generally classifiable as a primarily reductionistic textbook. This finding was consistent with the results of the SR analysis.

Table 17. Results of the ESR analysis of *Biology* by Brooker et al. (2011)

Brooker Ch 1	**Score**	**Category**	**Brooker Ch 54**	**Score**	**Category**
Front Graphic	8	IR	Front Graphic	8	DR
Fig. 1.1	8	IR	Fig. 54.1	12	IS
Fig. 1.2	8	IR	Fig. 54.2	11	IS
Fig. 1.3	8	IR	Fig. 54.3	14	IS
Fig. 1.4	8	IR	Fig. 54.4	15	DS
Fig. 1.5	8	DR	Fig. 54.5	11	IS/IR
Fig. 1.6	15	DS	Fig. 54.6	11	IS/IR
Fig. 1.7	13	IS	Fig. 54.7	8	IR
Fig. 1.8	8	IR	Fig. 54.8	7	DR
Fig. 1.9	9	IR/DR	Fig. 54.9	15	IS
Fig. 1.10	10	IR	Fig. 54.10	17	IS
Fig. 1.11	8	DR	Fig. 54.11	8	IR
Fig. 1.12	8	DR	Fig. 54.12	16	DS
Fig. 1.13	8	DR	Fig. 54.13	8	DR
Fig. 1.14	8	DR	Fig. 54.14	10	IR
Fig. 1.15	7	DR	Fig. 54.15	6	DR
Fig. 1.16	11	IR	Fig. 54.16	10	IR
Fig. 1.17	6	DR	Fig. 54.17	18	DS
Fig. 1.18	12	IR	Fig. 54.18	9	IR/DR
Fig. 1.19	7	DR	Fig. 54.19	8	IR
Fig. 1.20	5	DR	Fig. 54.20	8	IR
			Fig. 54.21	12	IR
			Fig. 54.22	10	IR
			Fig. 54.23	7	DR
			Fig. 54.24	7	DR
			Fig. 54.25	7	DR

The data below in Table 18 displays the results of the ESR graphic analysis of chapters 1 and 37 in the textbook *Campbell Biology: Concepts & Connections* (Reece et al. 2012). This textbook earned an overall average score of 10.6, out of a possible 20, for both chapters combined on the ESR analysis. This textbook actually scored slightly better when quantifying the total amount of systems-based graphics with 22.2% in Chapter 1 and 41.2% in Chapter 37. Chapter 37 still depicted a majority of graphics using a reductionistic perspective but with 41.2% demonstrating a systems-based perspective it comes closer to equal parts reductionistic and systems-based. Nevertheless, based on these data the Reece et al. *Campbell Biology* textbook

(2012) is generally classifiable as a primarily reductionistic-based textbook. The analysis of the ESR data is consistent with the findings from the SR data and corroborate the conclusion of this textbook being classified as primarily reductionistic in style and presentation of graphics.

Table 18. Results of the ESR analysis of *Campbell Biology* by Reece et al. (2012)

Reece Ch 1	**Score**	**Category**	**Reece Ch 37**	**Score**	**Category**
Front Graphic	7	DR	Front Graphic	17	IS
Fig. 1.1	9	IR	Fig. 37.3A	6	DR
Fig. 1.2	14	IS/IR	Fig. 37.3B	6	DR
Fig. 1.3	6	DR	Fig. 37.4	6	DR
Fig. 1.4	14	IS/IR	Fig. 37.5A	9	IR
Fig. 1.5	7	DR	Fig. 37.5B	9	IR
Fig. 1.6	8	IR	Fig. 37.6	10	IR
Fig. 1.7A	9	IR	Fig. 37.7	9	IR
Fig. 1.7B	5	DR	Fig. 37.8	13	IS
Fig. 1.7C	10	IR	Fig. 37.9	13	IS
Fig. 1.7D	7	DR	Fig. 37.10A	13	IS
Fig. 1.8	14	IS	Fig. 37.10B	13	IS
Fig. 1.9A	6	DR	Fig. 37.11A	14	IS
Fig. 1.9B	5	DR	Fig. 37.11B	11	IR
Fig. 1.9C	5	DR	Fig. 37.11C	11	IR
Fig. 1.9D	10	IR	Fig. 37.11D	11	IR
Fig. 1.9E	7	DR	Fig. 37.12A	9	IR/DR
Fig. 1.10	16	IS	Fig. 37.12B	15	IS
			Fig. 37.13A	7	DR
			Fig. 37.13B	14	IS
			Fig. 37.13C	6	DR
			Fig. 37.14	13	IS
			Fig. 37.15	6	DR
			Fig. 37.16A	12	IR
			Fig. 37.16B	13	IS
			Fig. 37.17	18	DS
			Fig. 37.18	8	IR
			Fig. 37.19	19	DS
			Fig. 37.20	13	IR
			Fig. 37.21	12	IR
			Fig. 37.22A	17	IS
			Fig. 37.22B	14	IS
			Fig. 37.23A	7	DR
			Fig. 37.23B	16	IS

Table 19 presents the results of the ESR graphic analysis of chapters 1 and 57 in the textbook *Biology 9th ed.* (Raven et al. 2011). This textbook also earned the second lowest average on the ESR with 9.6 out of a possible 20, for both chapters combined on the ESR analysis. Based on this qualitative rubric, the Raven et al. textbook (2011) uses primarily

Table 19. Results of the ESR analysis of *Biology* by Raven et al. (2011)

Raven Ch 1	**Score**	**Category**	**Raven Ch 57**	**Score**	**Category**
Front Graphic	5	DR	Front Graphic	6	DR
Fig. 1.1	14	IS	Fig. 57.1	9	IR/DR
Fig. 1.2	7	DR	Fig. 57.2	8	IR
Fig. 1.3	5	DR	Fig. 57.3	8	IR
Fig. 1.4	6	DR	Fig. 57.4	12	IR
Fig. 1.5	5	DR	Fig. 57.5	9	IR
Fig. 1.6	5	DR	Fig. 57.6	10	IR
Fig. 1.7	13	IS	Fig. 57.7	11	IR
Fig. 1.8	5	DR	Fig. 57.8	7	DR
Fig. 1.9	11	IR	Fig. 57.9	7	IR
Fig. 1.10	12	IS	Fig. 57.10	11	IR
Fig. 1.11	6	DR	Fig. 57.11	11	IS
Fig. 1.12	7	DR	Fig. 57.12	6	DR
Fig. 1.13	9	IR	Fig. 57.13	6	DR
			Fig. 57.14	9	IR
			Fig. 57.15	11	IR
			Fig. 57.16	11	IR
			Fig. 57.17	11	IR
			Fig. 57.18	11	IR
			Fig. 57.19	11	IR
			Fig. 57.20	11	IR
			Fig. 57.21	17	IS
			Fig. 57.22	14	IS
			Fig. 57.23	13	IS
			Fig. 57.24	19	DS
			Fig. 57.25	12	IR
			Fig. 57.26	14	IS

reductionistic graphics. Through analysis, Chapter 1 demonstrated 14.3% of the graphics being systems-based, while Chapter 57 included 22.2% systems-based graphics. Due to the low average number of graphics being categorized as systems-based, this textbook is also classified as primarily reductionistic. This textbook's categorization also corresponds to its classification based on the results of the SR.

Table 20 displays the results of the ESR graphic analysis of chapters 1 and 27 in the textbook *Biology: Life on Earth with Physiology* (Audesirk et al. 2011). The numbers obtained through the ESR of this textbook were similar to those obtained from the analysis of the Brooker et al. and Reece et al. textbooks. Still, with *Biology: Life on Earth with Physiology* (Audesirk et al. 2011) revealing an average of 11.6 out of 20 for both chapters combined on the ESR analysis.

Table 20. Results of the ESR analysis of *Biology: Life on Earth with Physiology* by Audesirk et al. (2011)

Audesirk Ch 1	**Score**	**Category**	**Audesirk Ch 27**	**Score**	**Category**
Front graphic	13	IS	Front Graphic	13	IS
Fig. 1-1	12	IR	Fig. 27-1	9	IR
Fig. 1-2	6	DR	Fig. 27-2	8	IR
Fig. 1-3	5	DR	Fig. 27-3	15	IS
Fig. 1-4	6	DR	Fig. 27-4	13	IS
Fig. E1-1	13	IS	Fig. 27-5	13	IS
Fig. E1-2	10	IR	Fig. 27-6	13	IS
Fig. 1-5	14	IS	Fig. 27-7	8	IR
Fig. 1-6	7	DR	Fig. 27-8	10	IR
Fig. 1-7	9	IR	Fig. 27-9	10	IR
Fig. 1-8	13	IS	Fig. 27-10	10	IR
Fig. E1-3	18	DS	Fig. 27-11	10	IR
Fig. 1-9	11	IR	Fig. E27-1	17	IS
Fig. 1-10	15	IS	Fig. 27-12	11	IR
Fig. 1-11	13	IR	Fig. E27-2	9	IR
Fig. E1-4	13	IS	Fig. 27-13	9	IR
Fig. 1-12	7	DR	Fig. 27-14	7	DR
			Fig. 27-15	17	IS
			Fig. 27-16	17	IS
			Fig. 27-17	17	IS
			Fig. 27-18	17	IS
			Fig. 27-19	14	IS

This was the highest overall average for the ESR analysis out of all five of the textbooks analyzed. This textbook also showed the highest percentage of systems-based graphics in both chapters. Chapter 1 included 35.3% systems-based graphics while Chapter 27 included 45.5%

systems-based graphics. With more than a third of the graphics in Chapter 1 being systems-based and nearly half in Chapter 27, this textbook comes the closest out of all five textbooks examined to being classified as a moderately systems-based text. Because the majority of the graphics included in this textbook are still reductionistic though, the overall classification is also reductionistic. This textbook comes closer than any of the other books examined on this scale to present nearly equal ratio of reductionistic graphics to systems-based graphics.

Table 21 reveals the results of the ESR graphic analysis of chapters 1 and 15 in the textbook *What is Life?* (Phelan 2010). Additionally, the Phelan textbook (2010) also demonstrated an overall average of 8.8, out of a possible 20, on the ESR for both chapters combined. This Phelan textbook displayed the lowest overall average on the ESR out of all five textbooks examined. The Phelan textbook (2010) was also the only textbook that contained zero graphics in Chapter 1 being classified as systems-based. Chapter 15 rated slightly better with 28.2% of the graphics scored as systems-based. The low scores for this textbook on both the SR and the ESR resulted in its consistent categorization as strongly reductionistic.

Table 22 is a descriptive summary of the data collected from the ESR analysis of graphics from all five textbooks. Overall the Audesirk textbook (2011) contained the highest percentage of systems-based graphics at 45.5% in Chapter 27, the ecology chapter, and the highest overall mean for both chapters. Alternately, the Phelan textbook (2010) represented the lowest mean for Chapter 1 at 0%, displaying no systems-based graphics at all. The Phelan text also displayed the lowest overall mean for both chapters and the lowest mean and mode for Chapter 1.

Table 21. Results of the ESR analysis of *What is Life?* by Phelan (2010)

Phelan Ch 1	**Score**	**Category**	**Phelan Ch 15**	**Score**	**Category**
Front Graphic	11	IS/IR	Front Graphic	8	IR
No Fig. Num.	7	DR	No Fig. Num.	6	DR
Fig. 1-1	5	DR	Fig. 15-1	10	IR
Fig. 1-2	5	DR	Fig. 15-2	13	IS
Fig. 1-3	6	DR	Fig. 15-3	12	IR
Fig. 1-4	5	DR	Fig. 15-4	12	IR
No Fig. Num.	8	IR	No Fig. Num.	8	DR
Fig. 1-5	5	DR	Fig. 15-5	7	DR
No Fig. Num.	5	DR	Fig. 15-6	5	DR
Fig. 1-6	5	DR	Fig. 15-7	7	DR
Fig. 1-7	5	DR	No Fig. Num.	8	IR
Fig. 1-8	5	DR	Fig. 15-8	8	IR
Fig. 1-9	5	DR	Fig. 15-9	15	IS
Fig. 1-10	5	DR	Fig. 15-10	7	DR
Fig. 1-11	5	DR	Fig. 15-11	14	IR
Fig 1-12	5	DR	No Fig. Num.	9	IR/DR
No Fig. Num.	8	IR	Fig. 15-12	15	IS
Fig. 1-13	5	DR	Fig. 15-13	16	IS
Fig. 1-14	8	IR	Fig. 15-14	13	IS
Fig. 1-15	8	IR	Fig. 15-15	10	IR
Fig. 1-16	5	DR	Fig. 15-16	18	DS
No Fig. Num.	5	DR	Fig. 15-17	13	IS
Fig. 1-17	6	DR	Fig. 15-18	13	IS
Fig. 1-18	6	DR	Fig. 15-19	20	DR
Fig. 1-19	5	DR	No Fig. Num.	9	IR
Fig. 1-20	5	DR	No Fig. Num.	10	IR
No Fig. Num.	5	DR	Fig. 15-20	9	IR
No Fig. Num.	10	IR	Fig. 15-21	12	IR
			Fig. 15-22	9	IR
			Fig. 15-23	12	IR
			Fig. 15-24	9	IR
			Fig. 15-25	9	IR
			Fig. 15-26	8	IR
			Fig. 15-27	13	IS
			Fig. 15-28	10	IR
			Fig. 15-29	11	IR
			No Fig. Num.	6	DR
			Fig. 15-30	14	IS
			Fig. 15-31	14	IS

Table 22. Summary of the results of the ESR analysis. Graphics were classified as systems-based when categorized as either Indirectly Systems-Based (IS) or Directly Systems-Based (DS). the highest value in each row category is in boldface. The lowest value in each row category is in italics.

Highest possible score = 20	**Brooker et al.**		**Reece et al.**		**Raven et al.**		**Audesirk et al.**		**Phelan**	
Chapter	Ch 1	Ch 54	Ch 1	Ch 37	Ch 1	Ch 57	Ch 1	Ch 27	Ch 1	Ch 15
No. Graphics	21	26	18	34	*14*	27	17	22	28	**40**
Mean	8.7	10.5	8.8	11.5	7.9	10.6	10.9	**12.1**	*6*	10.8
Mode	8	8	7	13	*5*	11	13	**17**	*5*	9
Overall Mean	9.7		10.6		9.6		**11.6**		*8.8*	
% system-based	4.8	34.6	22.2	41.2	14.3	22.2	35.3	**45.5**	*0*	28.21

The next 19 figures contain examples of graphics from each of the textbooks, those scoring the highest and lowest ratings in the ESR. This first graphic from Brooker et al. *Biology* (2011) Chapter 1 in Figure 11 is an example of a high scoring systems-based graphic. This graphic is meant to depict a biological hierarchy, showing how smaller parts come together to create larger parts and systems. The interconnectedness is explicitly shown by placing the images in an overlapping orientation, seamlessly connecting them. This image accurately displays an understanding of the earth's living and non-living systems and cycles. This graphic suggests empathy by focusing on non-human systems and interactions. It also emphasizes the complexity of the relationships between these levels and may even subtly suggest potential human effects by showing the clearing for a walkway or road. This graphic earned a score of fifteen out of twenty on the ESR.

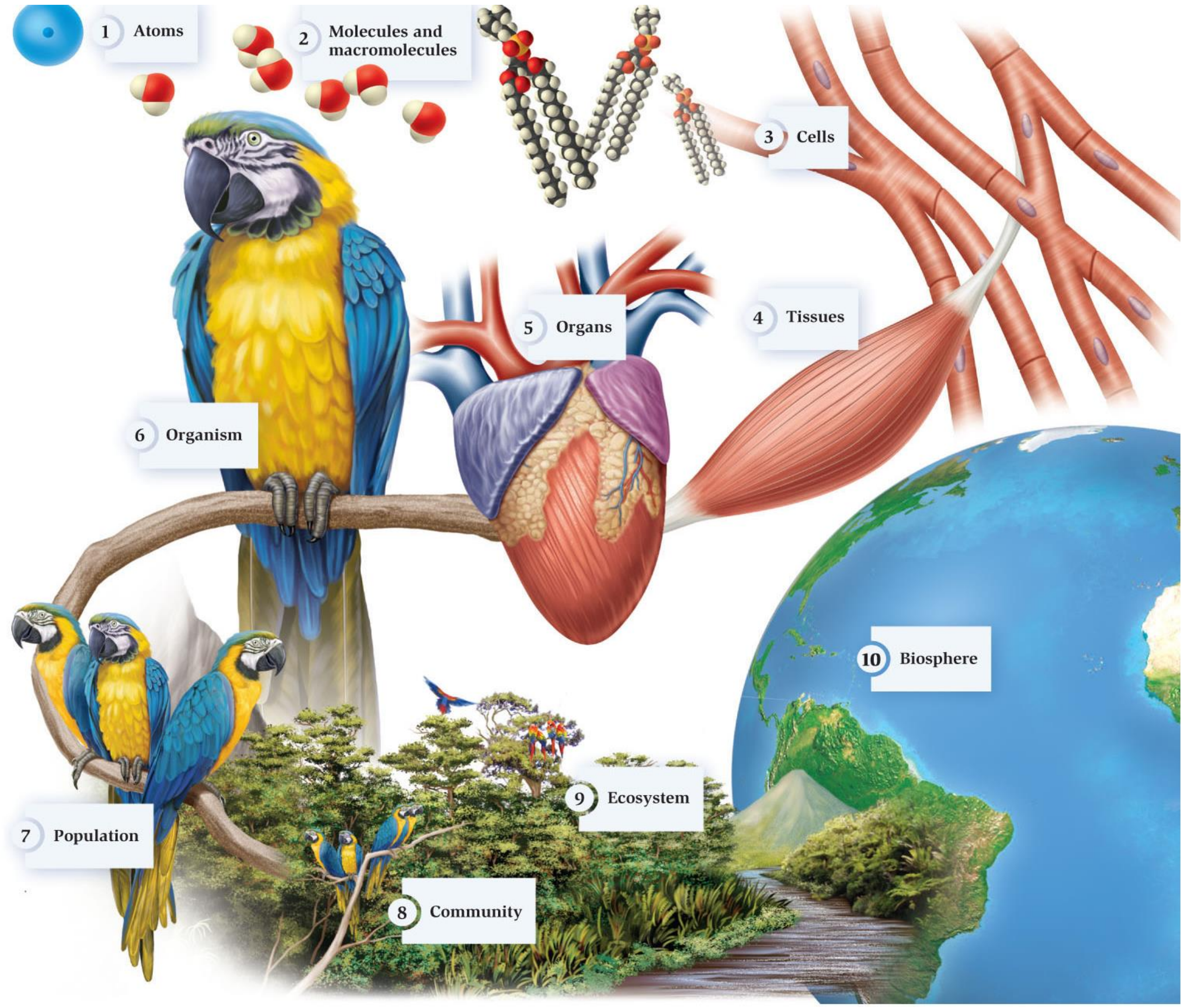

Figure 11. Example of high ranking system-based graphic from Brooker et al. *Biology* (2011), Chapter 1.

This second graphic from Brooker et al. *Biology* textbook (2011) in Chapter 1 is presented in Figure 12 is an example of a low scoring graphic on ESR. This graphic did show a biological phenomenon by displaying the *Aequorea victoria* jellyfish where the green florescent protein (GFP) was first discovered. The jellyfish is pictured in the top image and the spindle apparatus in a dividing cell is shown stained with the GFP in the lower image. This graphic also successfully made an invisible practice visible to the reader by demonstrating how this protein can be used to stain cells and make their internal processes apparent to researchers.

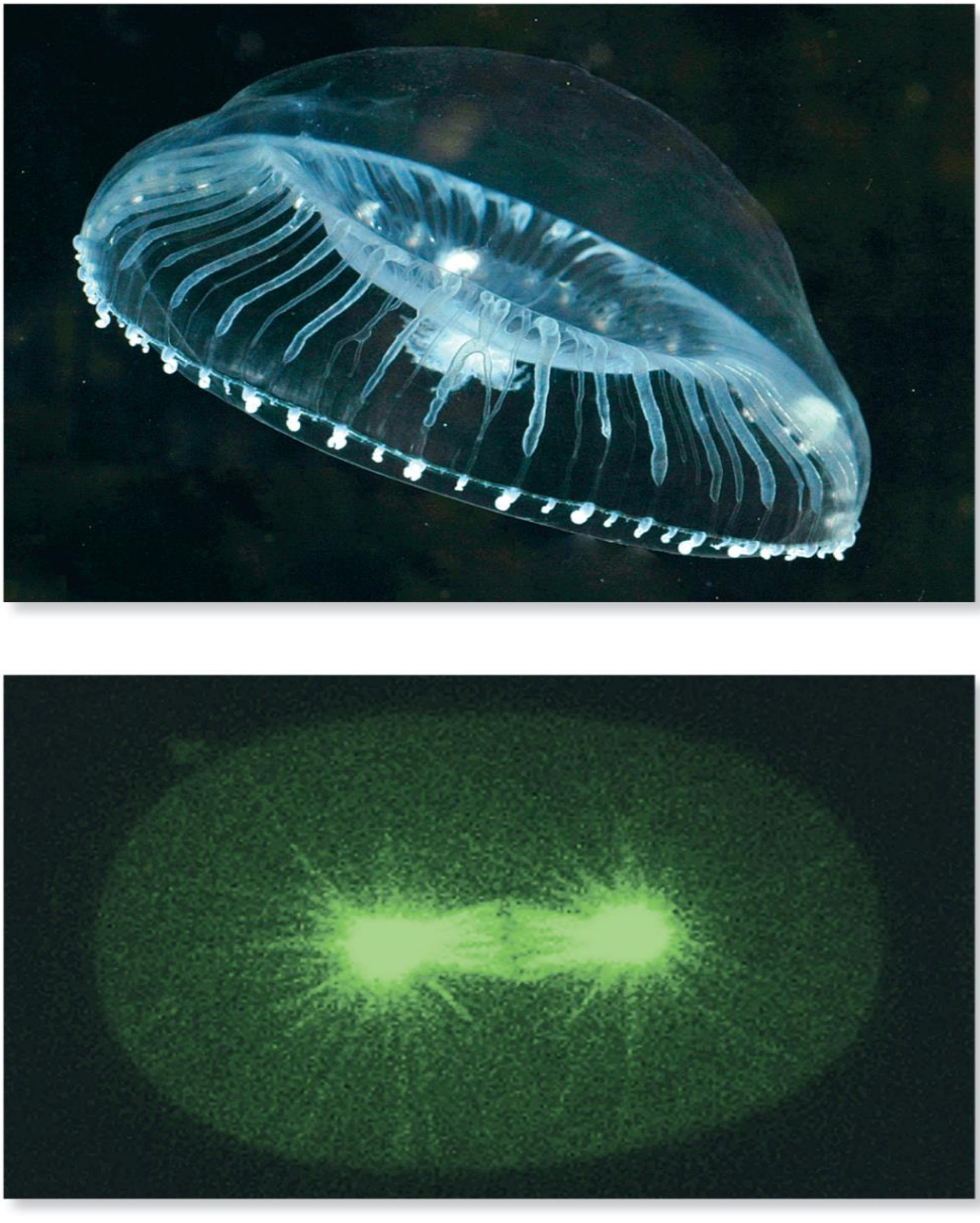

Figure 12. Example of low ranking non-systems-based graphic from Brooker et al. *Biology* (2011) Chapter 1.

Unfortunately, the graphic did not include any aspects of this animal's lifecycle or ecosystem or even portray it within the context of its natural habitat. This image also failed to even suggest any empathy towards the animal used to make this research possible. There were no indications of the possible negative effects of human collection and use of this animal, and no regard for other aspects of the jellyfish's ecosystem that could be affected from this usage. This graphic scored a seven out of twenty on the ESR.

In juxtaposition to Figure 12, Figure 13 is an example of a high scoring image on the ESR from Chapter 54 in the Brooker et al. *Biology* textbook (2011). This image does make some invisible practices visible such as some of the connections between abiotic and biotic factors within an ecosystem. Many students and readers of this text also many not be aware of the coevolution between predators and prey which emphasized through this illustration. This particular graphic also displays an understanding of the Earth's processes and its living and non-living cycles. Relationships are at the forefront of this image and the complexity of these relationships is highlighted, thus, implying that these natural functions may require specialized understanding and skill to maintain. Linkages between other organisms and humans are not explicitly depicted here although there is the implication that human interaction might offset this delicate balance.

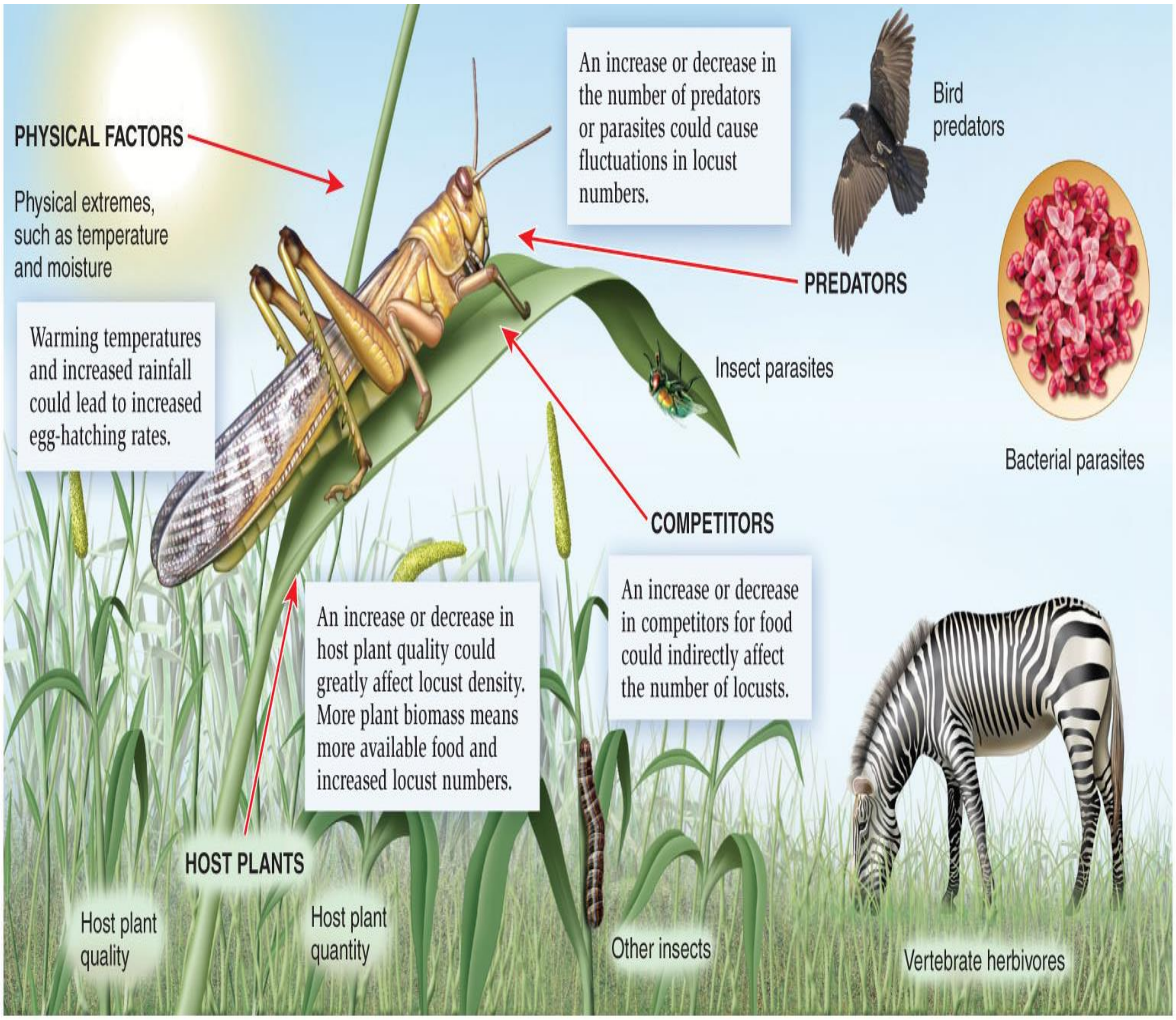

Figure 13**.** Example of a high ranking systems-based graphic from Brooker et al. *Biology* (2011) Chapter 54.

This graphic in Figure 14 from Brooker et al. *Biology* (2011) Chapter 54 is yet another example of a low scoring graphic on the ESR. This image is a prime example of a strongly reductionist graphic. By emphasizing the abiotic features of our biosphere it also deemphasizes linkages with humans and human actions. This image breaks down a complex process and displays it in its individual pieces in order to better demonstrate the complex concept of greenhouse effect. Unfortunately, by doing so, the actual complexity of the relationship between greenhouse effect and the living components of our biosphere is absent and is possibly lost to the non-science oriented reader. This image scored an eight out of twenty on the ESR.

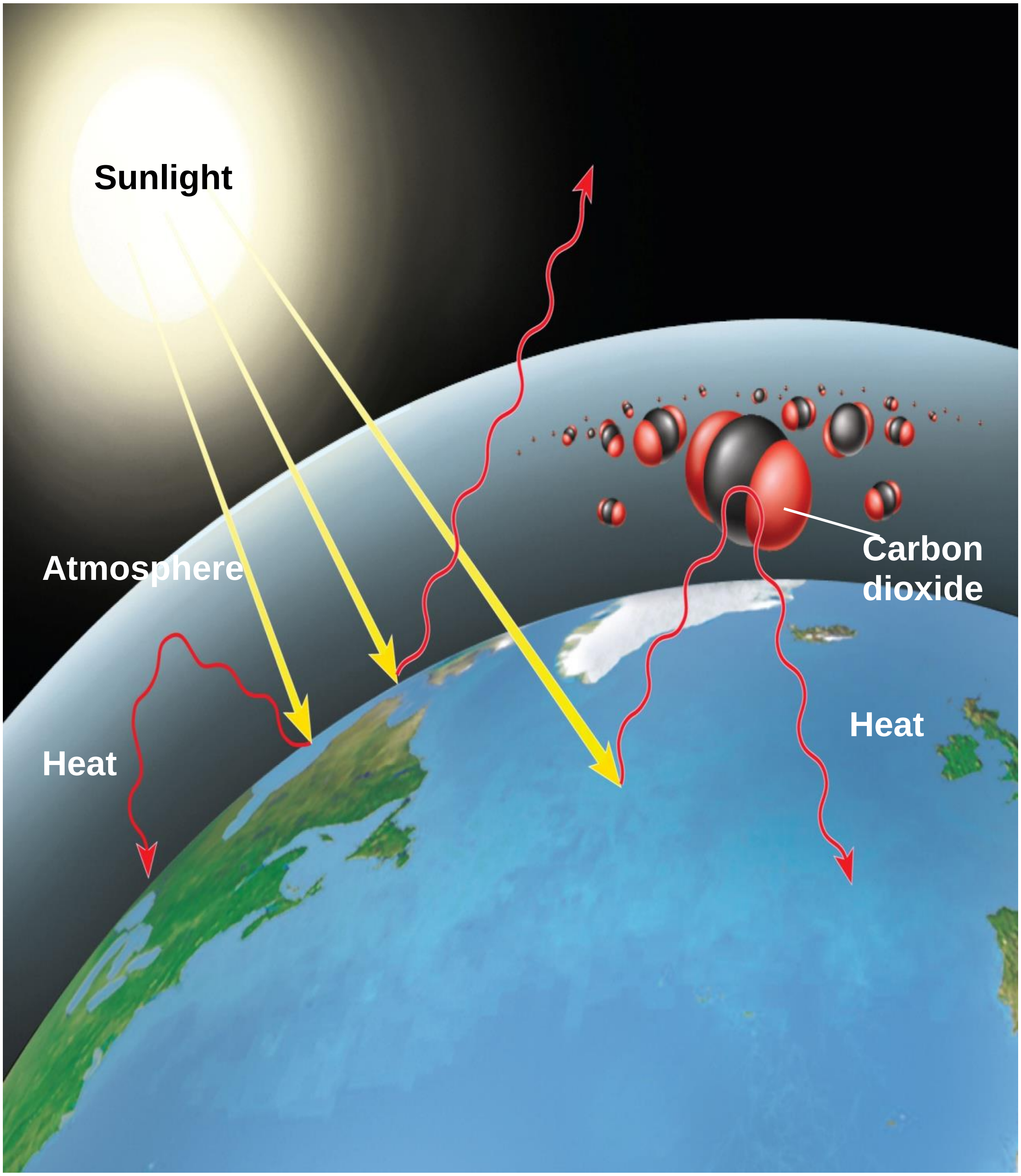

Figure 14. Example of a low ranking non-systems-based graphic from Brooker *Biology* (2011) Chapter 54.

In comparison, Figure 15 is an example of a relatively high scoring image on the ESR from Chapter 1 in the Reece et al. *Campbell Biology* textbook (2012). This graphic is an excellent example of a simple photograph successfully showing many aspects of systems-based thinking. This cover suggested empathy for other life forms by showcasing the invisible effects of the BP oil spill. Showing this cover also suggests that humans are not only linked to other organisms and their ecosystems but that humans have the potential to negatively affect their own environments through their actions. This image does not depict any cycles but it does suggest that the quality of ecosystem relationships can be delicate and complex enough to require special understanding. This graphic scored a sixteen out of twenty on the ESR.

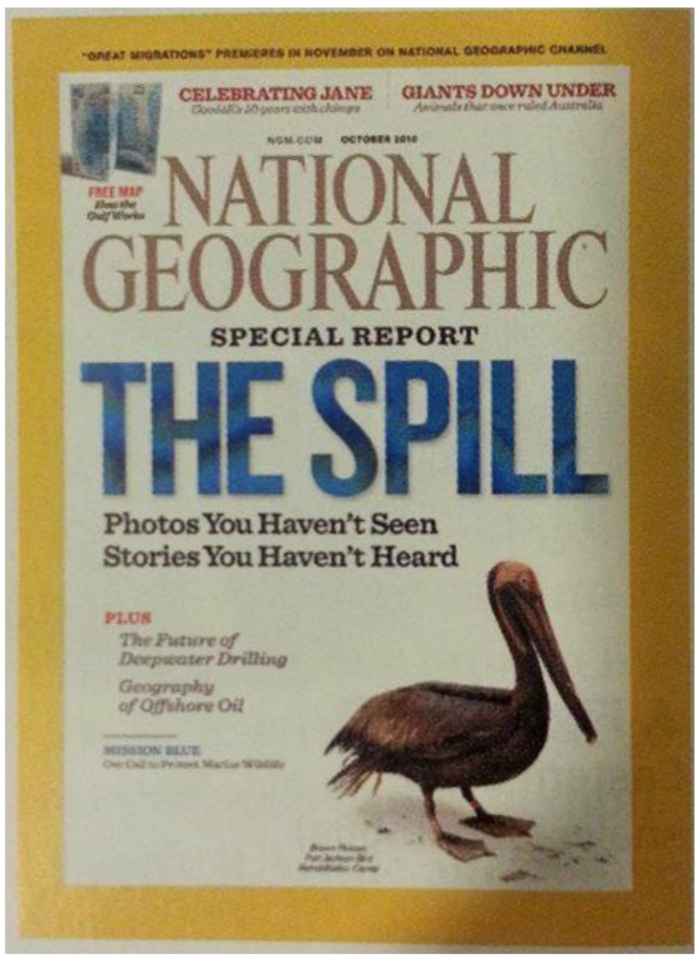

Figure 15. Example of a high ranking systems-based graphic from Reece *Campbell Biology* (2012) Chapter 51.

Figure 16 from the Reece et al. *Campbell Biology* textbook (2012) is another instance of a low scoring graphic from Chapter 1. This image is being used to demonstrate the appearance of an eastern coral snake and compares it to the appearance of the scarlet king snake which is very similar in reptile patterning and coloration. This image, while successfully demonstrating the differences and similarities between these two snakes, fails to illustrate any aspects of the snake's life cycle or its habitat which would have added dimension to the graphic. Furthermore, there is no suggestion of linkages to any abiotic factors or other organisms. Finally, humans do not feature in this image and are suggested to be completely separate from these animals. This image scored a five, the lowest possible score, out of twenty on the ESR.

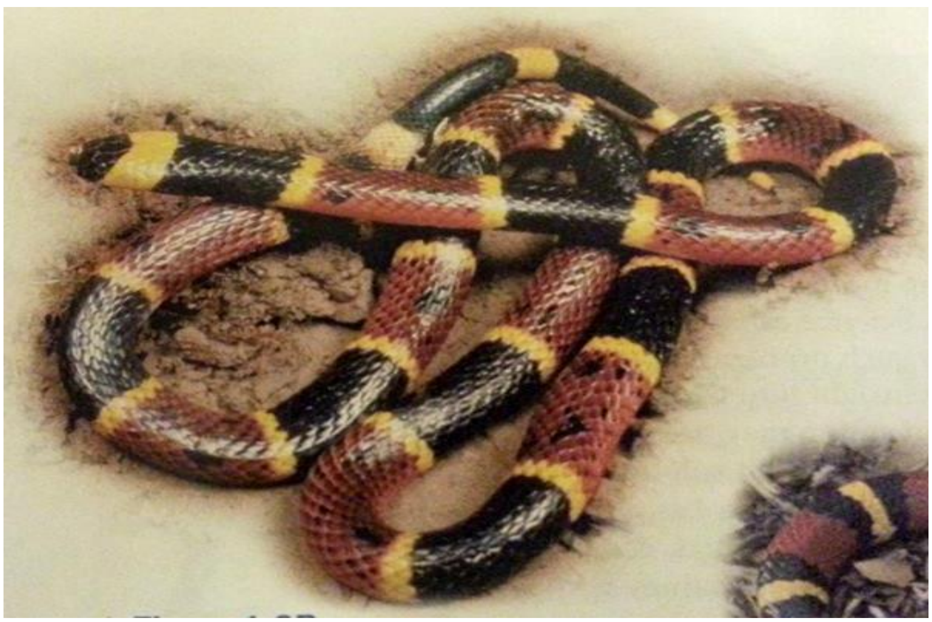

Figure 16. Example of a low ranking non-systems-based graphic from Reece *Campbell Biology* (2012) Chapter 1.

Figure 17 is an example of a novel graphic from Reece *Campbell Biology* (2012) Chapter 37, none of the other textbooks examined had any image similar to this one. This image not only accurately demonstrates the idea of trophic levels in an ecosystem, but it also highlights humans as being a key part of our ecosystem trophic levels. This graphic showcases how much more energy is required to support organisms at higher tropic levels, such as secondary consumers. By supporting meat eaters, the overall number of organisms at the top level decreases dramatically. Meaning that as a society people could feed more people by consuming more producers, i.e. plants, and fewer primary consumers, i.e. animals. This graphic shows part of a cycle and makes this invisible occurrence known to the reader. This graphic does an excellent job at showing exactly how humans can affect and even alter an ecosystem. This graphic scored an eighteen out of twenty on the ESR.

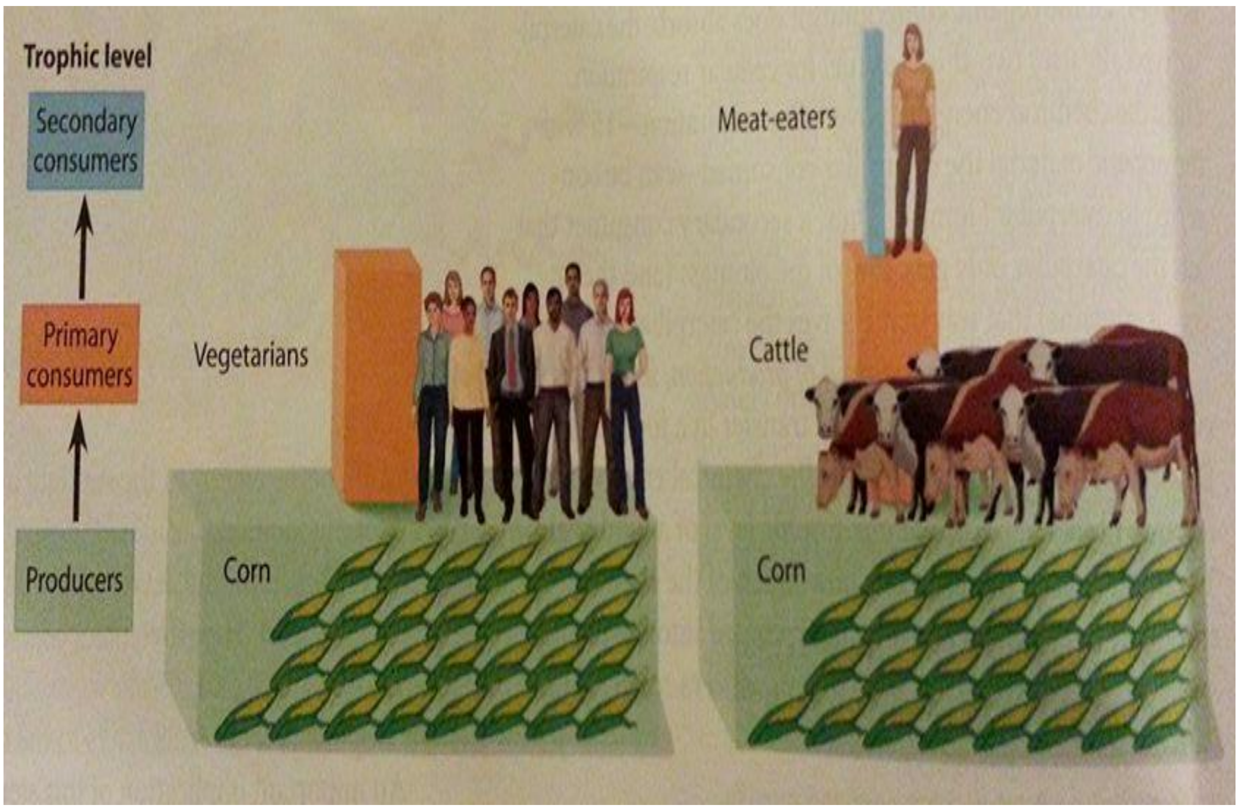

Figure 17. Example of a high ranking systems-based graphic from Reece *Campbell Biology* (2012) Chapter 37.

Figure 18 from the Reece et al. *Campbell Biology* textbook (2012) is an example of a low scoring graphic from Chapter 37. This image of a coral polyp is used as an example of the mutualistic relationship between the corals and dinoflagellates. The text goes on to mention the potential negative effects of human actions on the health corals but does not show through the picture any linkages to human ecosystems. There is no empathy for the organisms shown here in this graphic and no suggestion of the rest of the animal's lifecycle or ecosystem. Humans are removed from this graphic and maintained as distinct and separate from this ecosystem. The frailty and complexity of this unique and highly diverse ecosystem is missing in this image. This image scored a six out of twenty on the ESR.

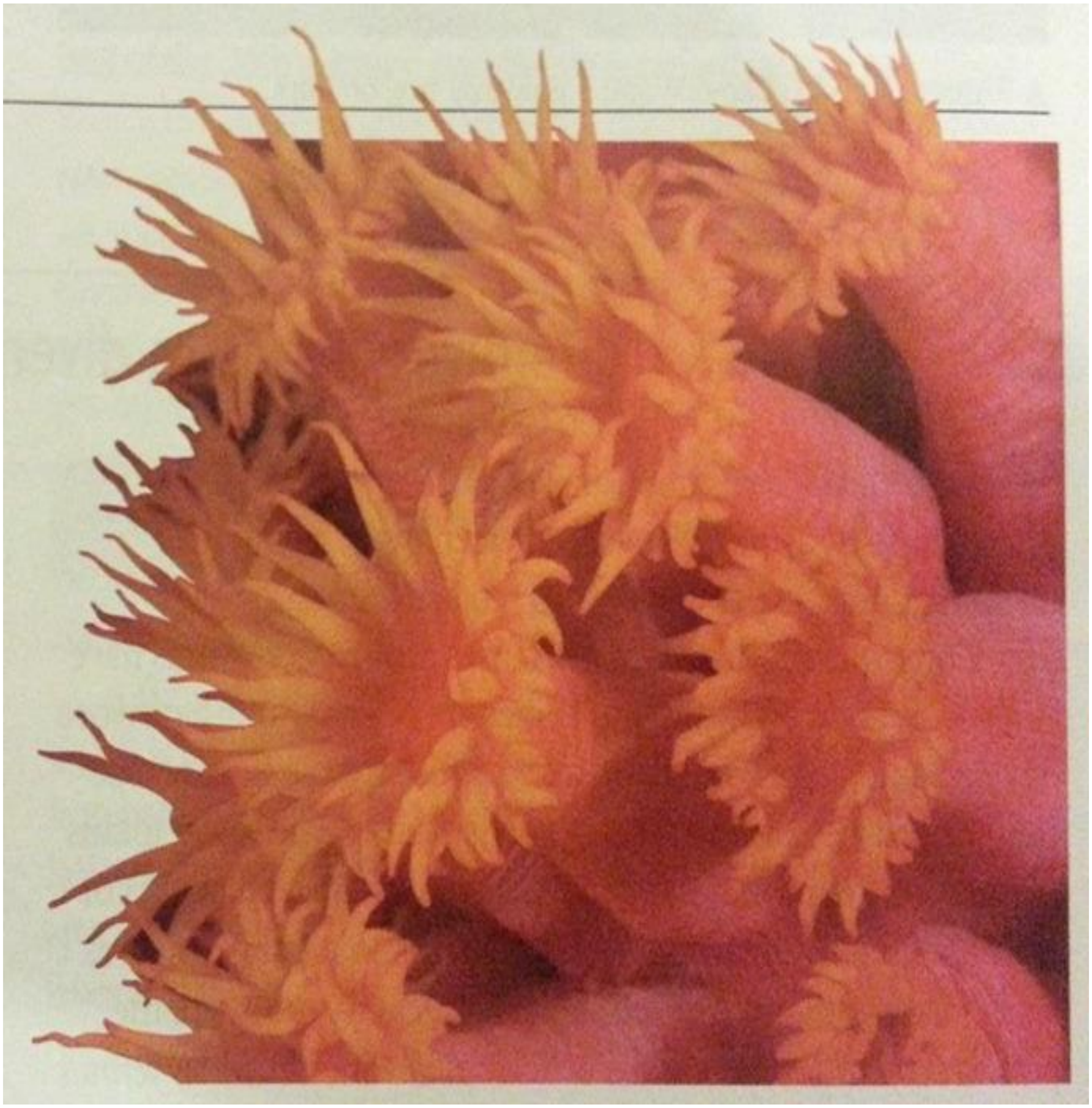

Figure 18. Example of a low ranking non-systems-based graphic from Reece *Campbell Biology* (2012) Chapter 37.

The graphic in Figure 19 from Raven et al. (2010) Chapter 1 is an excellent example of a high scoring graphic on the ESR. Figure 19 is a good example of a graphic that combines

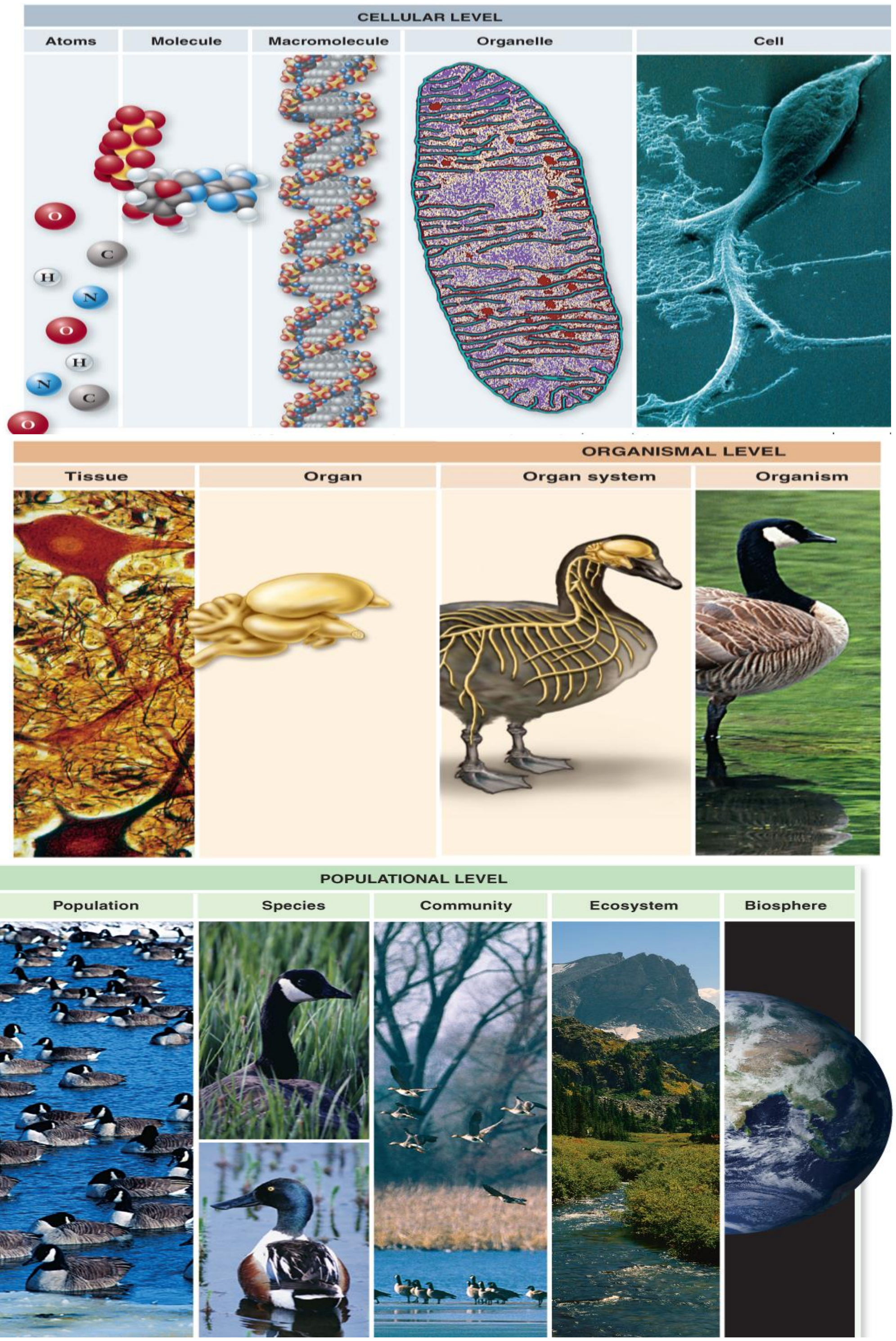

Figure 19. Example of a high ranking systems-based graphic from Raven *Biology* (2011) Chapter 1.

reductionist and systems-based ideas together into one comprehensive image. This image successfully indicates some empathy for other life forms by accurately displaying other life forms broken down into individual parts and integrated into the larger ecosystem and then into the biosphere context. It does not completely illustrate cycles and systems and only partly integrates abiotic factors with biotic ones. This image suggests the complexity that lies within these relationships but fails to include the potential affects of humans on these systems. This is a major omission since humans have had such a dramatic affect on the ecoystems in which they reside. This image was the highest scoring graphic for the Raven textbook in Chapter 1 (2010), it scored a fourteen out of twenty on the ESR.

Figure 20 is still another example of a low scoring graphic from the Raven et al. textbook (2010) in Chapter 1. Figure 20 is demonstrative of another highly reductionist image. This image of single-celled organisms and the cells of a plant reduces the living organism down to its simplest living parts. While this is a good tactic for demonstrating how these parts work independent of the whole organism, the larger holistic system appears to be missing. Since this image does not place these single cells into the context of their own ecosystem or even in the context of the organism from which they came, this makes it harder for the non-scientist reader to understand the larger system. There is also no suggestion of any cycles or systems show through this graphic. This graphic also does not designate any linkages between humans and any other organisms, suggesting that other organisms are not only separate but that human action may not affect any aspects of other ecosystems. This image scored a six out of twenty on the ESR.

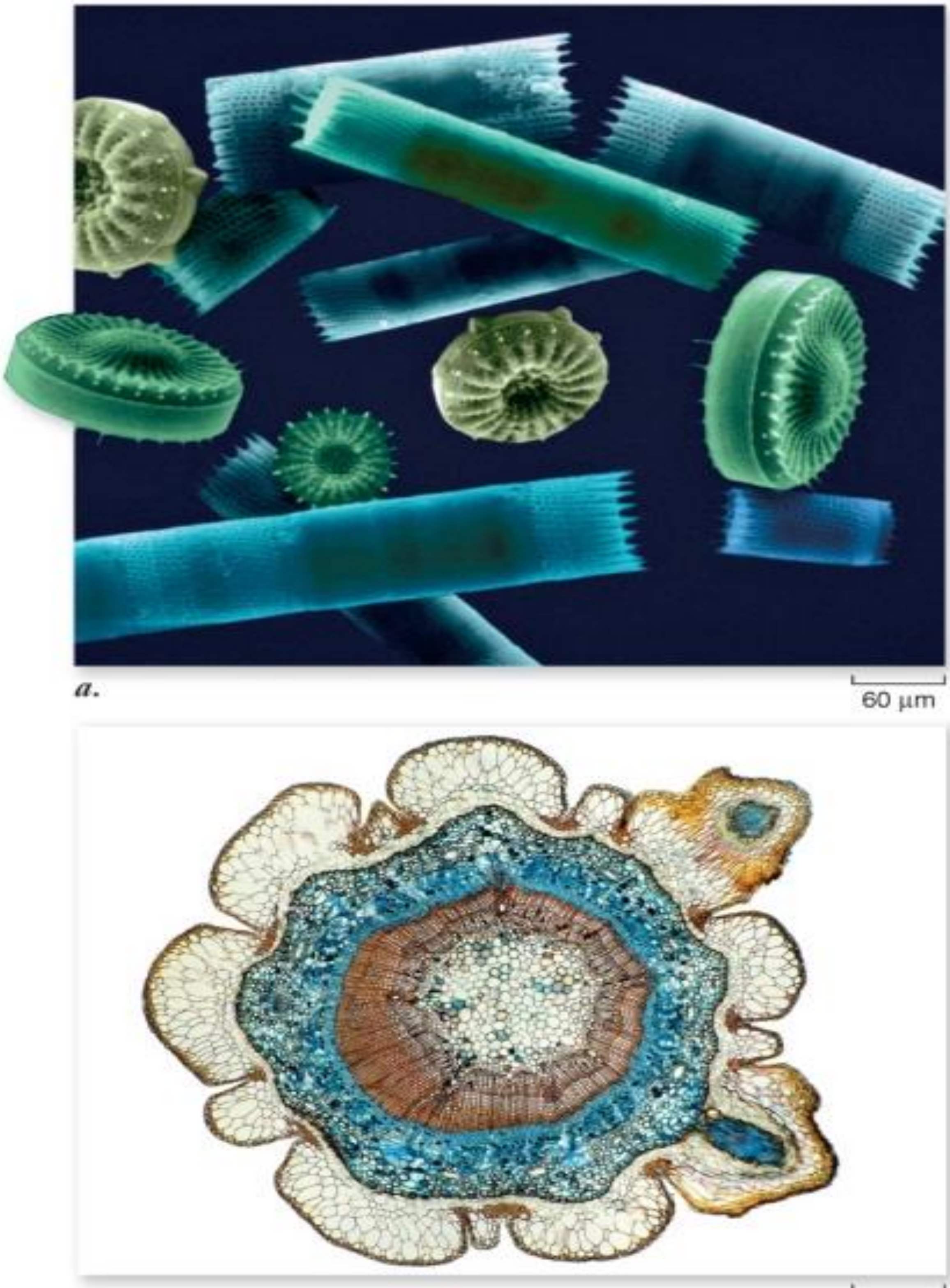

Figure 20. Example of a low ranking non-systems-based graphic from Raven *Biology* (2011) Chapter 1.

Figure 21 is an example of a high scoring graphic from the Raven et al. textbook (2011) in Chapter 57. This Figure displays empathy for other life forms by showing images of

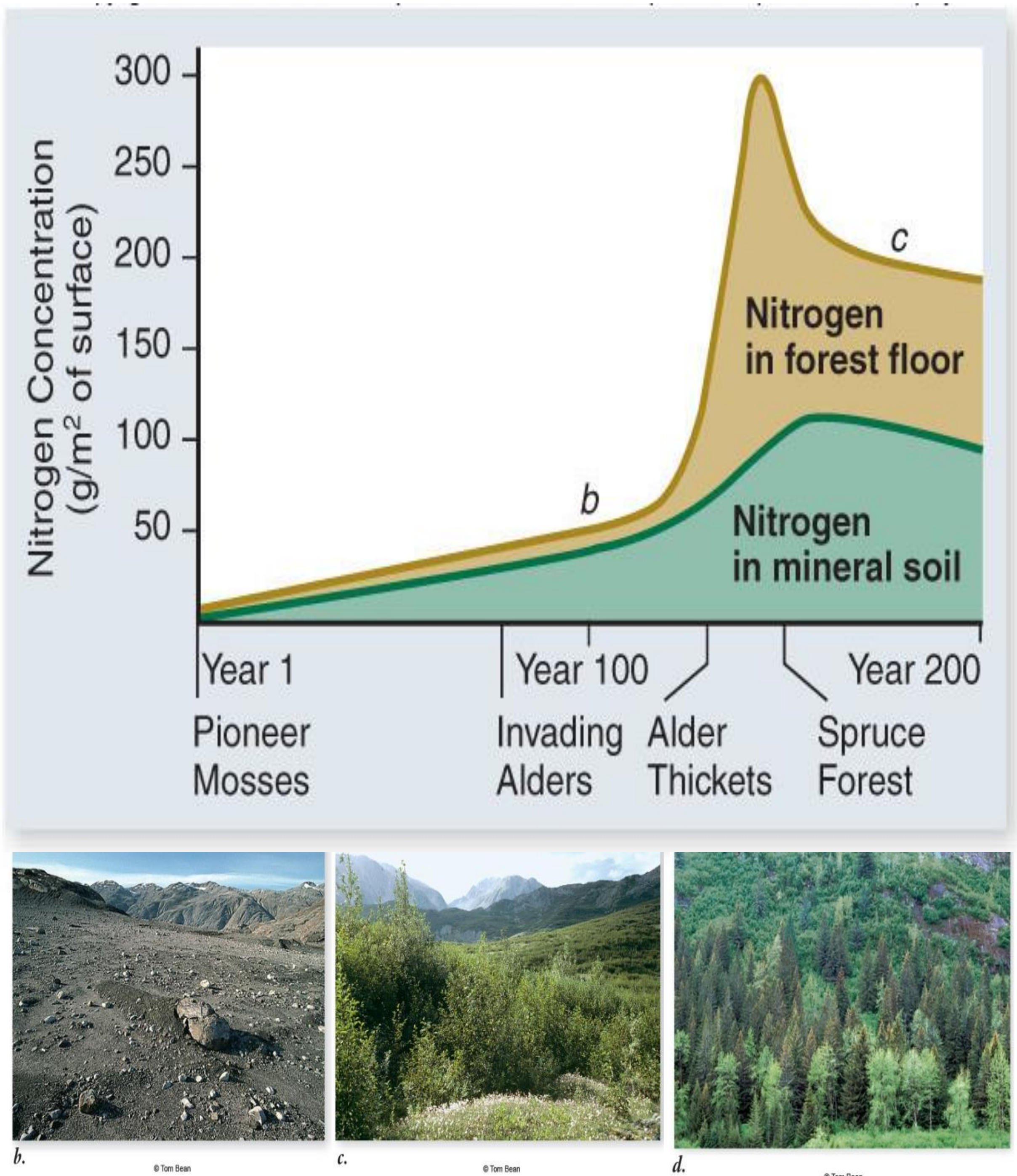

Figure 21. Example of a high ranking systems-based graphic from Raven *Biology* (2011) Chapter 57.

ecosystems outside of our own and living organisms other than humans. This graphic also makes apparent some invisible practices and predicts what may come of human actions in an ecosystem by including photographs of land that could have been affected by human actions. This graphic demonstrates a solid understanding of the Earth's process, living and non-living cycles and the complexity of those systems. Even though the photograph of the barren land in Alaska at the bottom left was not caused by human action, if suggested that similar types of succession could be seem in areas that have been cleared for human use. The use of three photographs showing various stages of primary succession after land has been cleared also places special emphasis on the relationships within every ecosystem and implies some degree of human responsibility. This image scored quite high, a nineteen out of twenty on the ESR.

Another sample of a low scoring image from the Raven et al. textbook (2011) can be seen in Figure 22. This image is from Chapter 57 is a simple photograph of a poisonous frog. While displaying the frog showcases the main purpose of the photograph, which is to highlight the visual component of a chemical defense system. Still, the picture does not specify the frog in its ecosystem context and does not indicate any linkages to any other animals and does not show any linkages to humans. Because the image is just that of a frog, a reader may not immediately comprehend that this animal is part of a larger system with cycles and linkages to other biotic and abiotic aspects of the biosphere. This photograph implies that the animal shown is independent of other systems and possibly immune to human's activity. This graphic scored a six out of twenty on the ESR.

Figure 22. Example of a low ranking non-systems-based graphic from Raven *Biology* (2011) Chapter 57.

Figure 23 is an example of a high scoring graphic from the Audesirk et al. *Biology* textbook (2011) in Chapter 1. This image demonstrates excellent empathy for other living systems by including a photograph of the endangered rosy periwinkle and its native habitat. This image also highlights some of the human caused destruction of habitat that has been directly linked to the decline in the population of rosy periwinkle. This graphic depicts the routine human practice of clear-cut logging and the effects of this practice on another organism, making this normally invisible practice visible to the reader. The visibly barren areas are striking and convey the message of an interconnectedness between human action and the success or decline of other species. This image could have scored slightly higher on the ESR by simply including aspects of the rosy periwinkle's lifecycle or other parts of its ecosystem. Non-science readers may find this image easier to relate or to understand more fully if it included some other aspects of the plant's ecosystem that would be adversely affects from the plant's population decline. This image earned the high score of eighteen out of twenty on the ESR.

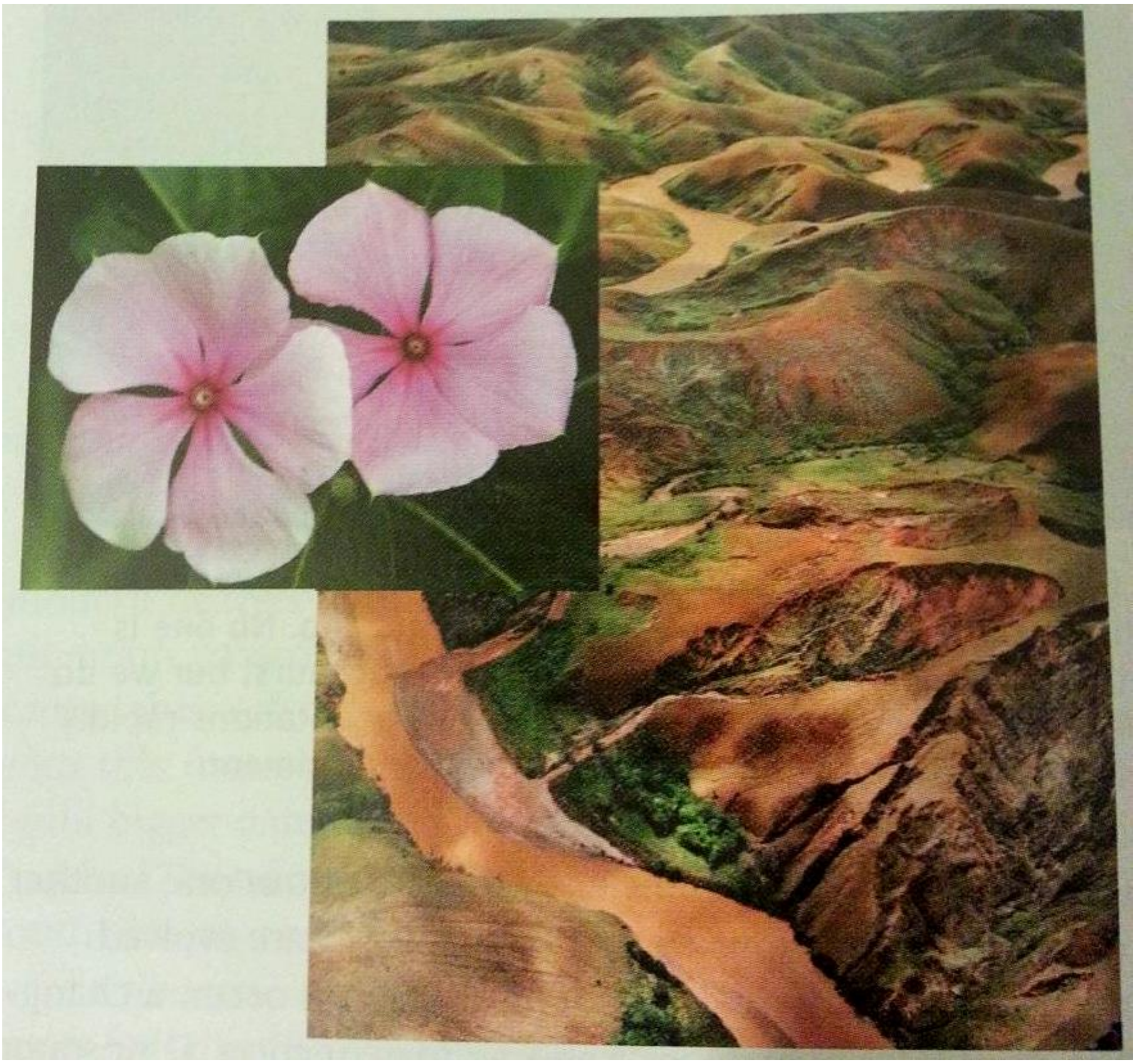

Figure 23. Example of a high ranking systems-based graphic from Audesirk *Biology* (2011) Chapter 1.

Figure 24 is an instance of a low scoring graphic from the Audesirk et al. *Biology* textbook (2011) in Chapter 1. This image is another example of extreme reductionism. While adequately illustrating the fundamental components of a eukaryotic plant cell, the graphic does not score well at including any system-based components. For example, there are no linkages shown there to other organisms, such as a comparable human or animal cell. Additionally, there are no images of the larger organism in order to place this single cell into its appropriate perspective. Again cycles are neglected and absent from this image and thus significantly downplayed in their importance to the organism. This image also strongly suggests that organisms can be easily broken down and studied without any regard to the entire organism or the ecosystem in which that organism may reside. This image scored a six out of twenty on the ESR.

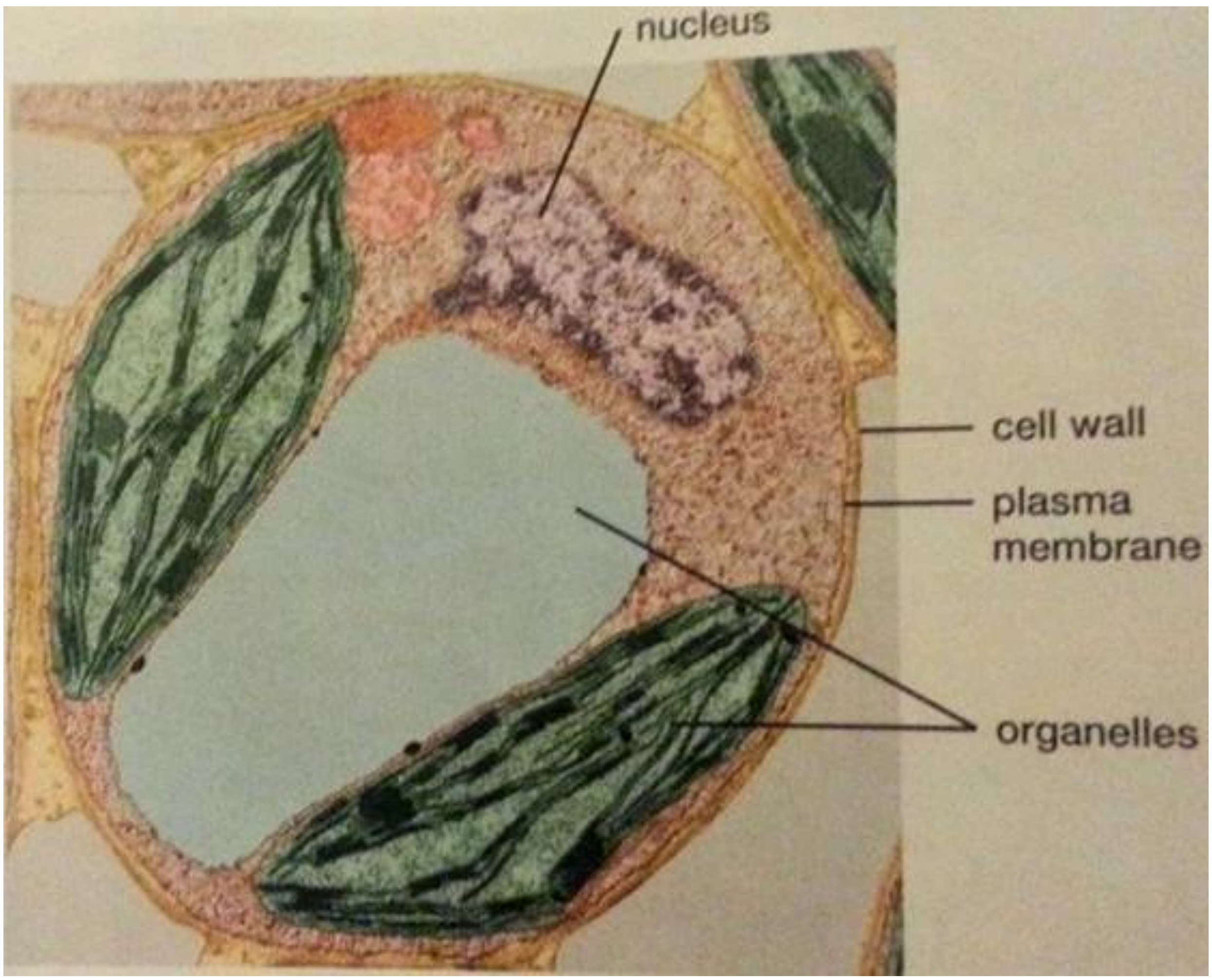

Figure 24. Example of a low ranking non-systems-based graphic from Audesirk *Biology* (2011) Chapter 1.

Figure 25 is another example of a high scoring graphic from the Audesirk et al. *Biology* textbook (2011). This graphic was selected from Chapter 27 as a primary example of a graphic that effectively displays a variety of habitats and includes biotic and abiotic features of each.

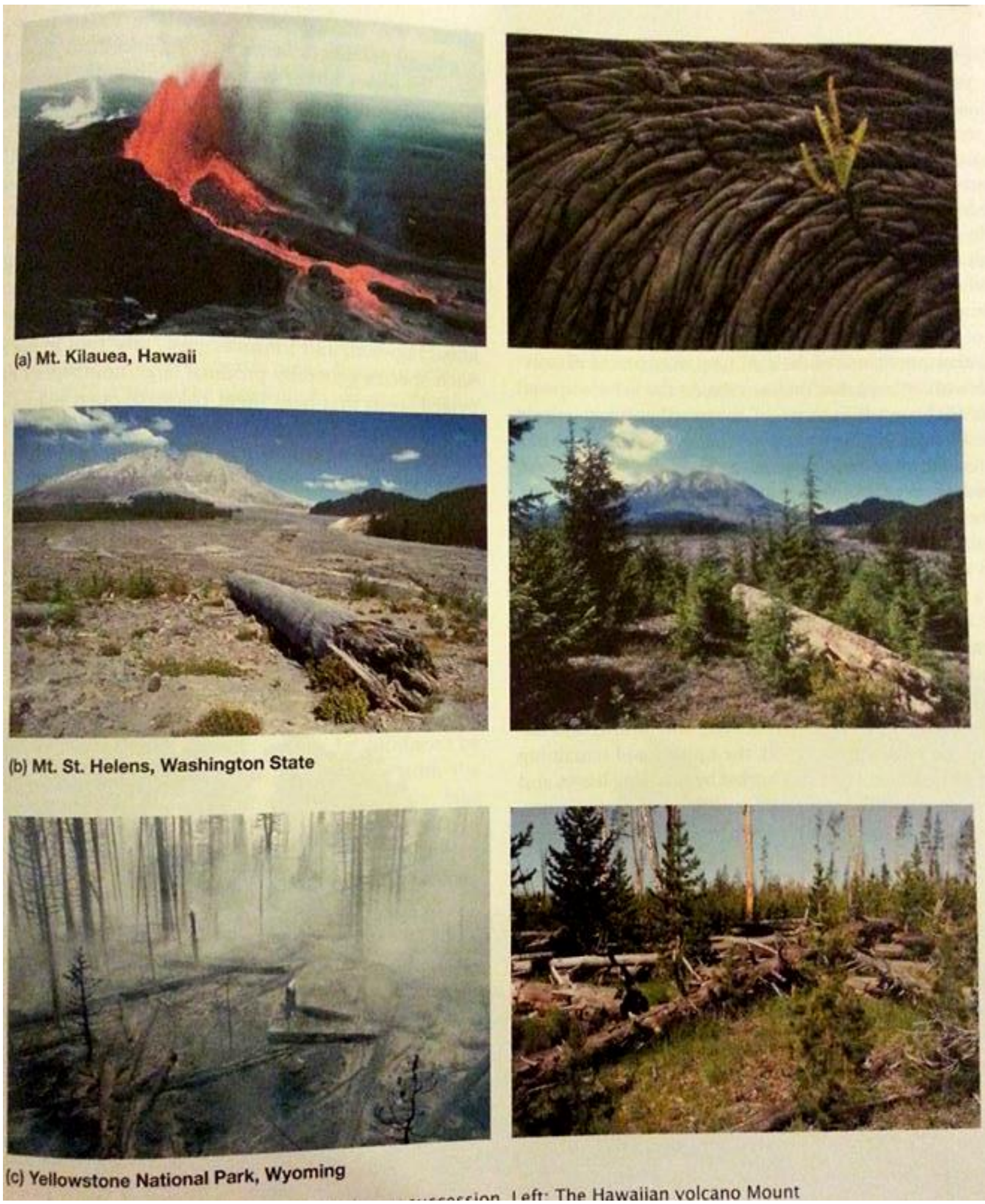

Figure 25. Example of a high ranking systems-based graphic from Audesirk *Biology* (2011) Chapter 27.

This graphic includes both before and after images of these habitats and accurately demonstrates examples of primary and secondary succession. Parts of these ecosystems are included in this image along with a suggestion of the complexity that underlies these communities and the ecosystems in which they reside. This graphic could increase its system-based elements by including habitats that have experienced human-generated disturbances or interference. Some human actions such as clear-cutting, strip-mining, and habitat degradation due to massive pollution could also be effective at showing primary and secondary succession in ecosystems. Such inclusion in the graphic would directly display linkages between human action and ecosystem health and development. Thus, such elements would actually be emphasizing the relationships that exist not just between other organisms and their habitats but also between humans, other organisms and their habitats. This image scored a seventeen out of twenty on the ESR.

An example of a low scoring image from the Audesirk et al. *Biology* textbook (2011) is selected for Figure 26. This graphic from Chapter 27 is included in this chapter to demonstrate examples of keystone species. The main purpose of this graphic is to highlight the disproportionate effect keystone species have on an ecosystem; that which can be seen when a keystone species is removed from its community. Removal of a keystone species typically results in major changes in the community structure within that ecosystem. This image effectively exposes these keystone species, but also removes these animals from their respective communities and lifecycles. Including more components of these animals cycles or ecosystems would have earned it a higher score in systems-based elements. This graphic scored a seven out of twenty on the ESR.

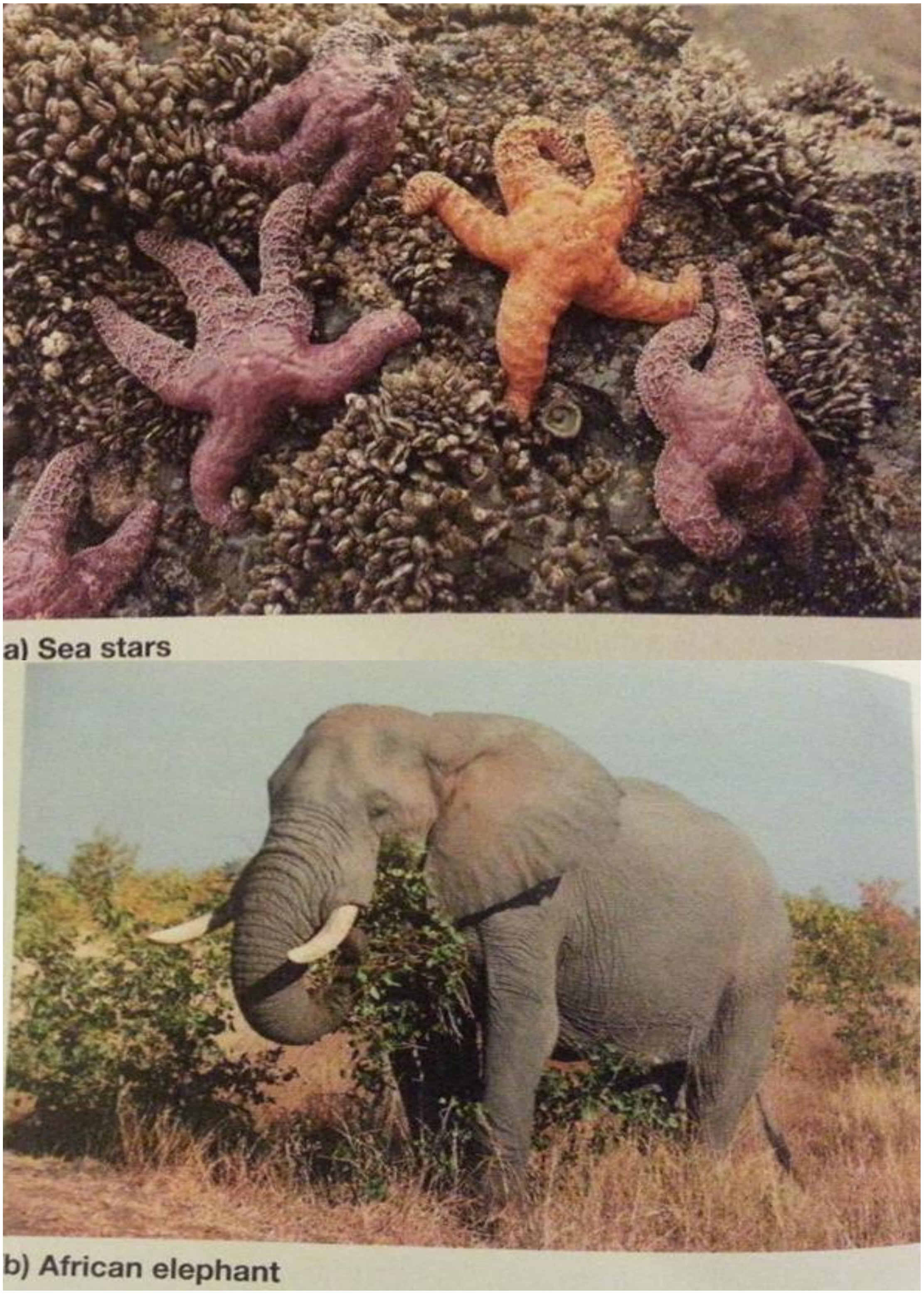

Figure 26. Example of a low ranking non-systems-based graphic from Audesirk *Biology* (2011) Chapter 27.

Upon examination of the Phelan *What is Life?* textbook (2010) I discovered that none of the graphic components of Chapter 1 scored high enough to be classifiable as systems-based graphics. Most of the images included in this chapter seemed heavily geared towards a young, non-science audience. The authors appeared to select graphics for inclusions based on their connections to the lives of typical college students. By doing this, all of the graphics shown were emphasizing human based habits and activities. There was only one graphic of any humans within a natural habitat, and most of the graphics did not disclose any linkages to other living things or other abiotic factors. There was also no suggestion of invisible practices or cycles within ecosystems in these graphics. Much of the complexity of natural systems seemed to be simplified, possibly subtly implying that these systems did not require special understanding and consideration. In the Phelan text there were a number of graphics that scored very low in system-based elements. The most commonly obtained score for graphics in Chapter 1 was a five out of twenty, the lowest possible score.

Figure 27 reveals an example of a low scoring graphic from Chapter 1 in Phelan *What is Life?* (2010). This graphic scored a five out of twenty due to its heavy focus on humans with no integration or linkages to any other organisms or ecosystems. This graphic was meant to emphasis how humans do use science to make good choices, such as in selecting food. While the graphic is successful in this respect, these types of heavily human focused images were far more common throughout this textbook than graphic that would have suggested or encouraged more system-based thinking in students.

Figure 27. Example of a low ranking non-systems-based graphic from Phelan *What is Life* (2010) Chapter 1.

Alternately, Figure 28 presents an example of a high scoring graphic from Chapter 15 in Phelan *What is Life?* (2010). This graphic earned the highest possible score of twenty on the ESR. Of all the graphics analyzed, this was the only one that most directly demonstrated the negative effects of human actions on the ecosystem in which they reside. This graphic was an accurate display of eutrophication in a freshwater system waterway, an increasingly common side-effect of fertilizer use in agriculture. This graphic accurately depicts all of the aspects of systems-based thinking: empathy for other life forms is shown through the inclusion of the dead fish, visibility in displaying this common side-effect of providing inexpensive food to humans highlights the consequences of human action on their own ecosystem, rendering many waterways unsuitable for drinking water and even unfishable is notable in the graphic, and processes in showing a detailed understanding of the relationship between the living things in an aquatic system and how they may be dependant or altered by changes in some abiotic components such as nutrients is also apparent in the graphic. Finally this graphic also demonstrates sustainability by emphasizing the delicate balance among humans, other organisms, and the environment. Graphic such as this one, might not only spark further interest and investigation into this problem, but may even spur students into environmental action.

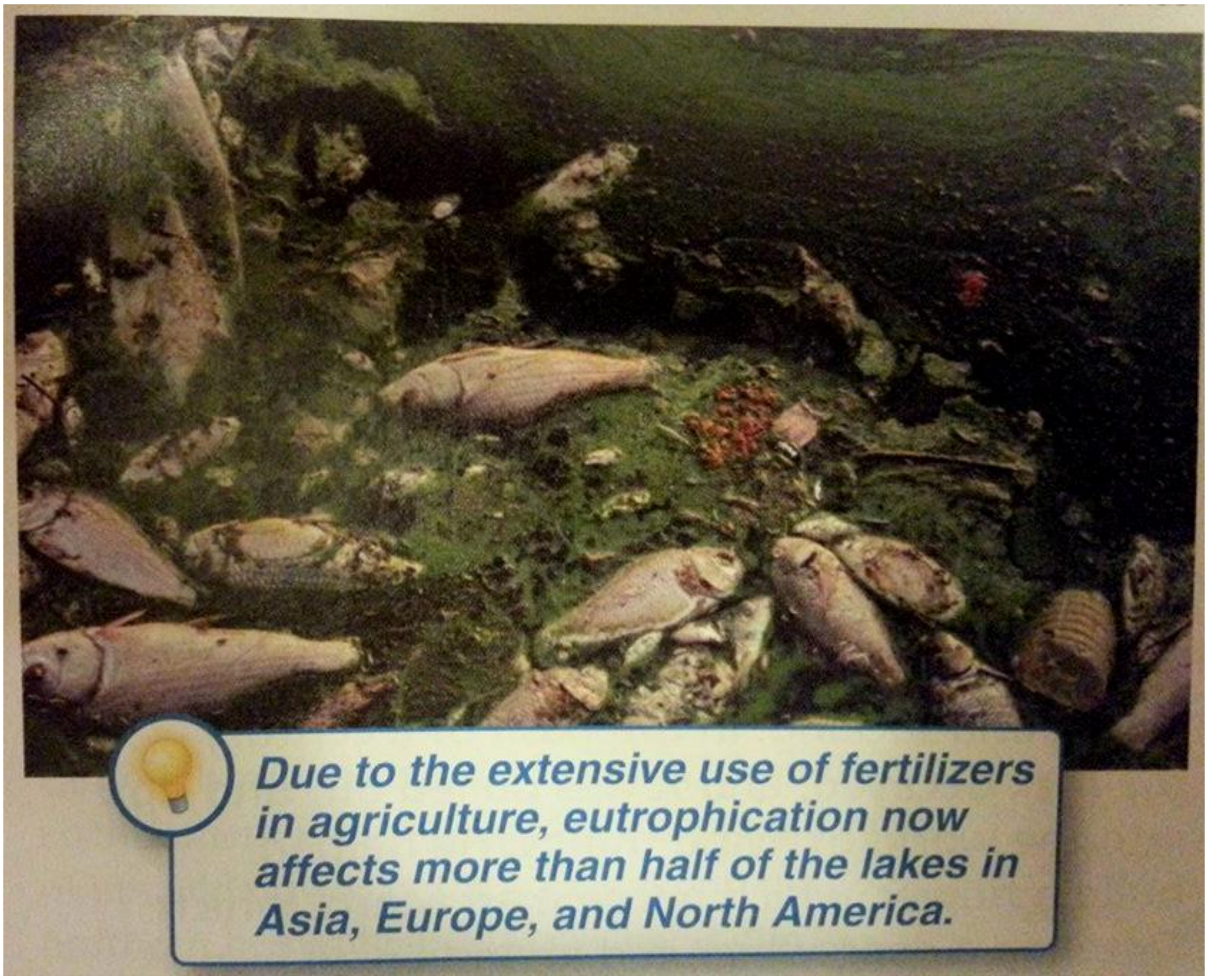

Figure 28. Example of a high ranking systems-based graphic from Phelan *What is Life?* (2010) Chapter 15.

Lastly, an example of a low scoring graphic from the Phelan *What is Life?* textbook (2010) is shown in Figure 29. The main purpose of this graphic is to include an example of a biological community. This image scored fairly low on the ESR because it simply shows the animals without including the context of their ecosystem. Typically a biological community includes several different species utilizing one section of a habitat, however this graphic only shows one species. This graphic would have scored higher in systems-based elements if it had included any linkages to other organisms or other aspects of the animals' life cycle in systems-based elements. This graphic scored a six out of twenty on the ESR.

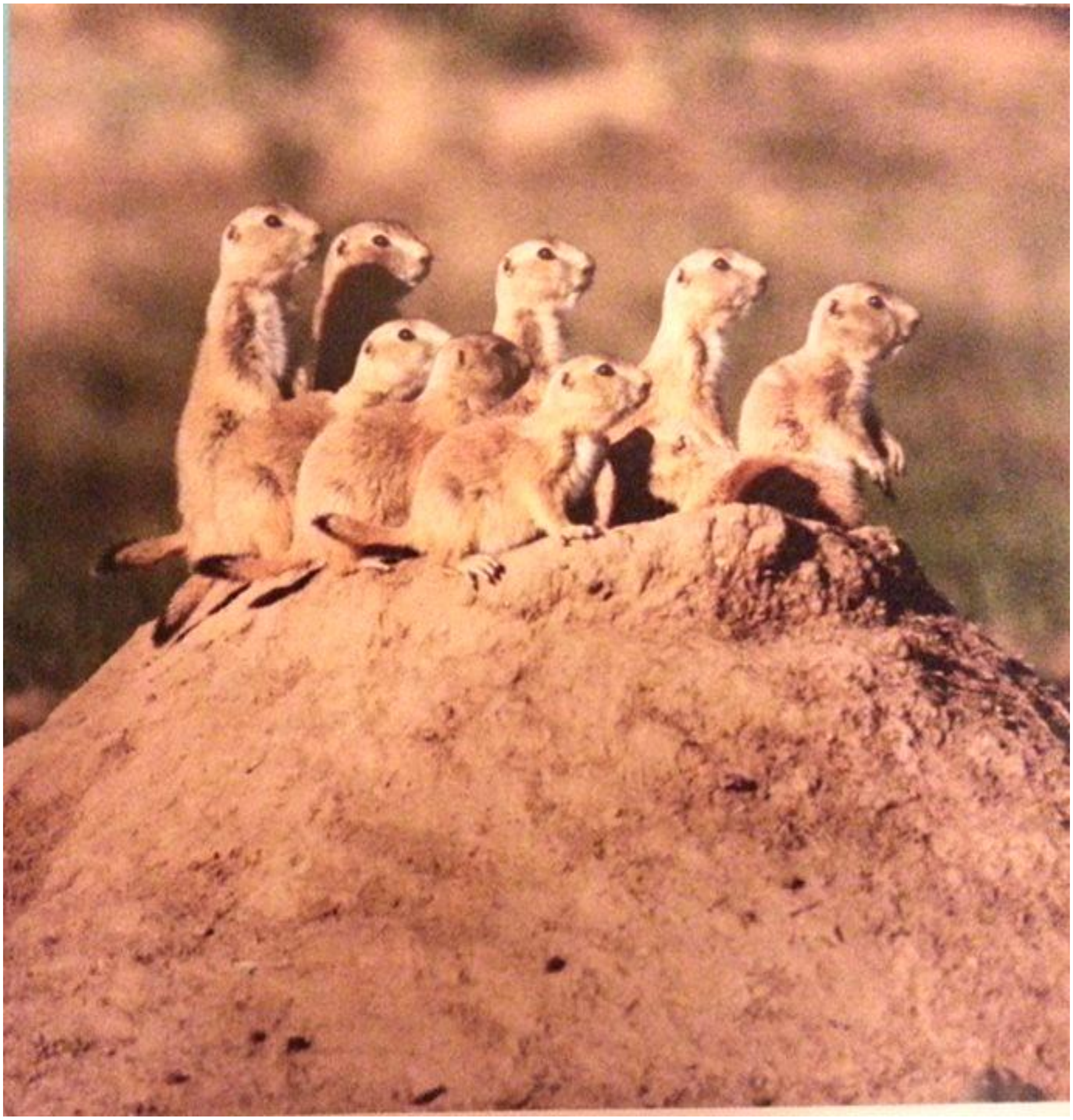

Figure 29. Example of a low ranking non-systems-based graphic from Phelan *What is Life?* (2010) Chapter 15.

The graphics presented above are illustrative examples of why each of these textbooks earned the scored that they did on each of the rubrics. The results of this analysis of the data generated from the SR were surprising in that none of the textbooks examined scored very high on this measure. Again the same result was found when using the data from the ESR. The findings from both of these rubrics were similar, essentially none of the textbooks examined had very many systems-based graphics. All of these popularly utilized biology textbooks tended to score very poorly in this aspect and could improve from greater inclusion of more systems-based elements. Alternately, the results of the Tuftian analysis were also surprising in that all of the textbooks examined scored very high on this measure. All of the textbooks included in this analysis were classified as moderately or highly Tuftian in graphical presentation. The next chapter will discuss summaries and conclusions of these findings and follow with suggestions and further recommendations to improve inclusion of systems-based thinking in textbooks and in classroom.

Chapter 5 Conclusions of Textbook Graphical Analysis

Completing the analysis of all five textbooks led me to a number of conclusions regarding how well each of these texts communicates systems-based scientific information and adheres to Tuftian principles. I will first discuss some of the conclusions reached from this analysis for each of the textbooks examined. I will then revisit my original hypotheses and discuss the implications of this research for each of these questions. Finally, I will propose suggestions for improving ecological literacy through textbooks and possible teacher education.

Analyzing the Brooker et al. textbook, *Biology* (2011), revealed relatively low scores on both the quantitative and qualitative systems-based rubrics. This textbook averaged a 9.3, out of a possible 18, for both chapters combined on the SR analysis. This text also averages a 9.7, out of a possible 20, for both chapters combined on the ESR analysis. The large majority of the graphics used in both chapters of this textbook were classified as either directly reductionistic or indirectly reductionistic with only 4.8% in Chapter 1 and 34.6% in Chapter 54 classified as either indirectly systems-based or directly systems-based. Based on these data the Brooker et al. textbook (2011) is generally classifiable as a primarily reductionistic textbook.

Showing these data generated from the SR in the form of a bar graph (Figure 9) helps to highlight the proportion of the graphics with each text that fell into the low, low/moderate, moderate/high, high categories. For the Brooker et al. *Biology* textbook (2011), this book had a majority of the graphics from Chapter 1 fall into the low/moderate category. Chapter 54 (Figure 10) shows a similar pattern except here one sees the largest number of graphics fell into the low category for systems-based elements. There were no graphics that scored in the high range on systems-based elements in either chapter. These data correspond directly with the conclusions reached from the ESR analysis. This information further bolsters the assessment that this textbook should be classified as primarily reductionistic.

The Reece et al. textbook, *Campbell Biology* (2012) also revealed relatively low scores on both the quantitative and qualitative systems-based rubrics. This textbook averaged a 9.5, out of a possible 18, for both chapters combined on the SR analysis and 10.6, out of a possible 20, for both chapters combined on the ESR analysis. This textbook actually scored slightly better when quantifying the amount of systems-based graphics with 22.2% in Chapter 1 and 41.2% in Chapter 37. Chapter 37 still contains a majority of graphics using a reductionistic perspective but with 41.2% demonstrating a systems-based perspective it comes closer to equal parts reductionistic and systems-based. Still I expected to see a higher percentage of graphics using a systems-based perspective when being used in a chapter that is intended to be entirely focused on ecology. Based on these data the Reece et al. textbook (2012) is generally classifiable as a primarily reductionistic-based textbook.

Examining the bar graph (Figure 10) created from the SR data collected from this textbook, *Campbell Biology* (Reece et al., 2012), better illustrates the distribution of systems-based graphics throughout each chapter. Chapter 1 shows the smallest overall number of graphics out of all the textbooks analyzed for Chapter 1. This bar also deliniates the largest number of graphics were scored in the low range on systems-based elements. Figure 10 demonstrates the same trend with graphics being classified as low occupying the largest space on the bar. Figure 10 does display a small number of graphics in this chapter recieving the ranking of high in systems-based elements. Chapter1 in this textbook did not contain any graphics reaching the level of high in systems-based elements as can be seen in Figure 9. The analysis of this bar graph for *Campbell Biology* further corroborates the analysis of data from the ESR, thus categorizing this textbook as primarily reductionistic.

The textbook, *Biology*, by Raven et al. (2011) demonstrated slightly higher scores than the two previously described textbooks. This textbook averaged a 10.4, out of a possible 18, for both chapters combined on the SR analysis. This was the highest overall average on the SR out of all five textbooks. Although this textbook did have the highest overall average on the SR, it also rated the second lowest average on the ESR with 9.6 out of a possible 20, for both chapters combined on the ESR analysis. This indicates that when using a more qualitative classification method, the Raven et al. textbook (2011) uses primarily reductionistic-based graphics. Chapter1 demonstrated 14.3% of graphics being systems-based. The graphics in Chapter 57 included 22.2% being classified as systems-based. The low average number of graphics being categorized as systems-based in this textbook still classifies this textbook as primarily reductionistic.

The bar graph in Figure 10 created from the SR data also visually summarizes the distribution of systems-based graphics throughout each chapter from *Biology* (Raven et al., 2011). The classification of the systems-based elements in Chapter 1 of this textbook underscores the complete lack of any graphics in the moderate/high or high ranges. Graphics in Chapter 57 did include small number in the scoring in the high range and a larger amount scoring in the moderate/high range as is shown in Figure 10. Chapter1 includes low scoring graphics more frequently than any other type when using the SR. Chapter 57's most frequently used graphics fall into the low/moderate category. These data further bolster the ESR assessment of this textbook as being primarily reductionistic in its presentation style and tone.

Biology; Life on Earth, by Audesirk et al. (2011) averaged a 9.8, out of a possible 18, for both chapters combined on the SR analysis. This average was in line with the averages of the

Brooker et al. and Reece et al. textbooks. This textbook also earned an average of 11.6 out of 20 for both chapters combined on the ESR analysis. This was the highest overall average for the ESR analysis out of all five of the textbooks analyzed. This textbook also displayed the highest percentage of systems-based graphics in both chapters. Chapter1 included 35.3% systems-based graphics while Chapter 27 included 45.5% systems-based graphics. With more than a third of its graphics in Chapter 1 being systems-based and nearly half in Chapter 27 this textbook comes the closest out of all five textbooks examined to being classified as a strongly systems-based text. Because the majority of the graphics included in this textbook are still reductionistic, then the overall classification is also reductionistic. Still, this textbook comes closer to being classified as moderately or highly systems-based than any of the other textbooks examined on this scale.

The Audesirk *Biology; Life on Earth* (2011) included the largest number of moderate/high scoring graphics in Chapter 1 of all the textbooks included in analysis. Chapter 27 does include the largest number of high scoring graphics out of all of the ecology chapters examined. This chapter also uses low/moderate graphics more than any other category of graphic. This textbook, Audesirk *Biology; Life on Earth* (2011), overall, includes more systems-based graphics than any of the other textbooks examined. Even in light of this, this textbook is still classifiable overall as directly reductionistic due to the majority of its graphics still having been classified as directly and indirectly reductionistic.

The Phelan textbook, *What is Life* (2010) demonstrated some of the lowest averages out of all five of the textbooks analyzed. This textbook averaged an 8.4, out of a possible 18, for both chapters combined on the SR analysis. This was the lowest overall average on the SR out of all five textbooks. Additionally, the Phelan textbook (2010) also showed an overall average of 8.8, out of a possible 20, on the ESR for both chapters combined. This too was the lowest overall average on the ESR out of all five textbooks. This textbook was also the only textbook to demonstrate zero graphics in Chapter 1 being classified as systems-based. Chapter 15 rated slightly better with 28.2% of the graphics scored as systems-based. The low scores for this textbook on both the SR and the ESR cause it to be categorized as strongly reductionistic.

The bar graphs representing the distribution of system based-elements in the Phelan textbook Chapters 1 and 15 are displayed in Figures 9 and 10. The bar for this textbook is striking in that it clearly demonstrates that even though Phelan had by far the most graphics included out of any of the first chapters, it also included very few graphics that scored in the moderate/high range and none that scored in the high range. For Chapter 1 in the Phelan textbook the most frequently used graphics were those scored in the low range. The Phelan text used more low scoring graphics than any of the other textbooks total number of graphics combined.

The Phelan textbook, *What is Life?* (2010), presented an interesting problem for introductory biology instructors. This textbook seemed to be very accessible, user friendly, and written to appeal to the average college student. By including many examples of how biology can be seen and used in everyday life, the author is effectively conveying some basic biological concepts without alienating the reader with too much scientific jargon. Additionally, using examples and images of people engaged various activities that can be placed into a biological context is an excellent tool for integrating real life with more abstract scientific ideas. Alternately, this textbook also significantly downplays systems-based biology, emphasizing humans as distinct and separate from other organisms and the non-living components of our ecosystem. This may give the non-science reader very little respect or consideration of whole ecosystems and the huge part that humans play in those systems.

Chapter 15 (Figure 10), in the Phelan *What is Life?* textbook (2010), includes more graphics scored as moderate/high than the first chapter, but still includes a medium amount of moderate/high scored graphics. The largest number of graphics still fell into the low category for this chapter, with the second largest group of graphics being placed into the low/moderate category. Even though the focus of this chapter is ecology, it still did not have any graphics that scored in the high category. This was the same result that was seen in the Brooker et al textbook (2011). The bar graph representation of the data from the SR further substantiates the conclusions drawn from examination of data generated from the ESR classifying this book as primarily reductionistic.

One of the most unexpected findings of this study was that none of the books examined seemed to include a majority of systems-based graphics. All of the books included in this research, and subsequently also the most commonly used introductory textbooks based on Amazon.com textbook sales, were classified as primarily reductionistic after completing an in depth analysis of the graphics included with the two selected chapters. One might have also expected to see a stronger use of systems-based graphics to be included in the textbooks chapters on ecology. Although there was a greater inclusion of moderate/high graphics here, systems-based graphics were not the most commonly used graphic in these chapters. This was another unexpected finding of this research.

Another unexpected finding of this research was revealed through the analysis of the TR data. It became clear through the analysis of this data that almost all of the graphics examined scored strongly in accordance with Tuftian good graphics principles. This was consistent when considering graphics that did include numeric data elements and those that did not include any numeric data. All five of the books examined had average scores in the 9.5-9.9 range out of a possible 10 for graphics that did not use any numeric data. While the graphics that did use numeric data had a score range of 15.8-18 out of a possible 20. All five of the textbooks examined thus can be classified as highly Tuftian with respect to the graphics included in these selected chapters.

Returning to my first research questions, I have reached a number of conclusions regarding this analysis and propose recommendations for future textbook authors and for introductory biology instructors. First, I will revisit my first research question; what is a typical volume of graphic content within a sample of collegiate introductory biology textbooks that uses systems-based thinking? The first rubric, the Quantitative Systems-Based Rubric (SR), was created specifically to address this first research question. Based on the data obtained through the use of this rubric on all five textbooks, there seems to be a small amount of systems-based graphics included in any of the textbooks examined. Approximately 25% of the graphics examined could be classified as indirectly or directly systems-based. Which indicates that the majority of textbook graphics are still strongly reductionistic.

Shifting focus to my second research question; how do select popular, collegiate introductory biology textbooks better utilize a mixture of reductionist thinking and systems thinking through graphics? Of the chapters included in this analysis the graphics earned an average score of 9.5 out of a possible 18 when examined for systems-based elements. These data again demonstrated a low degree of inclusion for systems-based elements in the graphics that are included in traditional introductory textbooks. Instead of showing a balanced mixture of reductionist and systems-based graphics within each chapter most all of the chapters examined tended heavily towards inclusion of reductionistic graphics with a minimal amount of systems-based ones.

Turning to my final research question; how many sample collegiate introductory biology textbooks use reader-centered graphics that correspond to classic Tuftian principles? Based on the results of the Tuftian Rubric (TR), all of the textbooks examined did adhere strongly to Tuftian recommendations about creating effective graphics. The average score on this rubric for all of the graphics examined without numeric data was a 9.7 out of 10, suggesting strongly Tuftian graphics in all five of the textbooks. This is one area of analysis that did not appear to need any recommendations for improvement. All of the chapters analyzed showed surprisingly high scores on this aspect of the research.

Recommendations

In order to create graphics that include a greater degree of systems-based components authors should focus on the five elements of systems-based thinking as illustrated by Capra (Center for Ecoliteracy, 2004). Authors can work to increase the degree of empathy depicted through a graphic by incorporating non-human animals along with humans in realistic ecosystems. Displays of humans in natural style settings can be helpful for a reader to relate to the concept at hand, but they should still be reminded that almost every action that humans make may directly or indirectly affect the habitat on which we depend so heavily. For example, graphics should show the entire animal in addition to whatever part is the focus of the graphic, like a single cell. If an image of a single cell is used and the larger organism is not featured then the reader might not realize that the cell itself may have certain features specific to that organism, features that might not be transferable to all cells.

Visibility is another area in which authors can work to improve in their graphics. Visibility can be increased by explicitly showing the reader how human actions can affect other organisms. Even when looking at the graphics within the ecology chapters of these textbooks, there were only a very small number that featured common human-caused ecological problems such as pollution, carbon dioxide induced global warming, overharvesting, or habitat degradation and destruction. Naturally occurring ecological disturbances were far more likely to be depicted in graphics such as volcanoes, fires, flooding and weather fluctuations. This area could be greatly improved through a more honest display of the by far most destructive organism on this planet, human beings.

Graphics could also be improved through further inclusion of another systems-based element, consequences. Rarely did any of the graphics examined include any type of predictive elements, warning the reader of ecosystem changes that might be seen if an action were taken. Most of the footage included in these chapters was post hoc, or after the fact. Therefore, even when graphics included displays of the types of changes that humans are capable of producing in our own ecosystems, there were very few graphics that showed predictive images. Showcasing that which *could* happen if certain human actions were taken was sorely missing from all of these books. For example, showing an image of what the landscape might look like in the future if humans continue to clear cut much of the old-growth forest in the world and how those actions might not only affect human food or medicine supplies but might also adversely affect the ecosystems of other organisms that humans may rely upon.

Textbooks could also be improved with a more complete incorporation the complex processes that are uniquely tied to every ecosystem. Each ecosystem contains a number of complex food webs, processes, and cycles containing living and non-living aspects. Several of the graphics did successfully include parts of cycles but may times neglected to incorporate living and non-living elements into those graphics. Living components are inevitably directly and indirectly linked to non-living components. The importance of this relationship between living and non-living parts in these cycles cannot be overemphasized. Living things could not persist without non-living aspects of ecosystems such as sunlight, water, minerals and gasses. Further incorporation of more complete cycles and processes detailing a greater degree of complexity would help improve the recognition of this systems-based aspect in textbook graphics.

Lastly, sustainability is the final component of systems-based graphics that could benefit from greater emphasis with these textbook graphics. Sustainability in graphics highlights the need for cooperation among different humans communities in order to truly realize human responsibility when it comes to ecosystem problems. This feature would more directly emphasize how humans can directly and indirectly affect the quality of the web of relationships among humans and other organisms. This aspect can explicitly depict humans as responsible for ecosystem alterations and degradation. True sustainability incorporates various human societies, other organisms and non-living parts of an ecosystem to appropriately illustrate this concept.

Some of the textbooks included in the research appeared to be slightly more inclusive when it came to using systems-based graphics. While other textbooks seemed to pay little attention to the style or type of graphical elements included within each chapter. I would implore textbook authors to give more critical examining when considering the type, style and amount of graphics included in a book. With this in mind, authors can present a more balanced perspective of the biological sciences.

For example, the Phelan textbook while being a good example of a small volume, non-traditional textbook, it still failed to convey connectivity between humans and other organisms. The Audesirk et al. textbook actually used a number of high systems-based graphics, some of which were considered excellent in this area. Still this textbook failed to include enough of these type of graphics to give the book a more holistic feel. The Reece et al, Brooker et al., and Raven et al. were all fairly comparable in scores. All three of these textbooks would benefit from greater inclusion of directly systems-based graphics and also from revision of some of the current graphics to give them a broader perspective. These findings are significant given that all five of the examined textbooks are respected in the field of college-level biology and frequently utilized by college-level biology educators (via personal communication). Modifying existing graphics or adding new graphics could greatly increase students' exposure and possibly improve their understanding of the interconnectedness of biological systems and cycles. There is no part of biology that exists in a vacuum. Cycles, processes, and interconnections need to be obvious and major part of every science student's education. Modification and closer attention to textbook graphics can be a start in that direction.

Some future research could also help improve the validity and generalizability of these findings. The rubrics created here could be further validated through evaluation for systems-based assessment properties with other educators and researchers in the field. Repeatability could be improved through testing with other textbooks and publishers. Exploration of possible pseudoreplication issues could be evaluated by comparing textbook results with respect to publisher.

Some other recommendations to improve student ecological literacy are not just limited to systems-based graphics in textbooks. Changes to teacher education could include more explicit inclusion of ecological education and a more holistic perspective of the sciences. Teachers will frequently reflect this perspective through their own teaching (Duschl, 1990). Outdoor education and the inclusion of more sustainability education opportunities for students has frequently been seen as a strong means to promote ecological literacy in students (Flint, McCarter, Bonniwell, 2000). Greater use of these educational tools may promote ecological literacy in students and even adults.

Educators could also become better versed in textbook evaluation and textbook selection. As this research study has indicated, rubrics created can be utilized to evaluate the graphics in science textbooks. Utilization of a more critical process of textbook selection may also help alter students' perspective of the environment. Students would benefit from a textbook that would help them to view the world less of a set of parts available for people to use and consume without any repercussions, and more as made up of many complex processes and cycles that can be changed and affected by human action. In addition, consumers of science textbooks can be taught to use these rubrics, thus becoming more critical of the graphics contained in the current materials they use.

This research has demonstrated that some of the most commonly used introductory, college, biology textbooks are not inclusive enough of a systems-based perspective, even within chapters dedicated to conveying strongly systems-based topics such as community ecology this held true. This is a critical area for college students due to increasing environmental problems in this country and relatively low levels of environmental awareness in students and adults alike (Coyle, 2005). Imparting students with a feeling of responsibility is imperative for them to demonstrate ecologically responsible, conscientious thought and ultimately ecological action. Ecological literacy is an area that demands attention in the area of education and could benefit from greater attention from educators and a wider incorporation in our core curriculum.

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Appendix A

Textbook chapters with graphics selected for analysis

Textbook	Authors	Chapter	Graphic	Page
Biology, 2nd ed.	Robert Brooker, Eric Widmaier, Linda Graham, Peter Stiling	1 - An Introduction to Biology	Front Graphic	1
			Fig. 1.1	1
			Fig. 1.2	1
			Fig. 1.3	2
			Fig. 1.4	2
			Fig. 1.5	3
			Fig. 1.6	5
			Fig. 1.7	6
			Fig. 1.8	6
			Fig. 1.9	7
			Fig. 1.10	7
			Fig. 1.11	8
			Fig. 1.12	9
			Fig. 1.13	10
			Fig. 1.14	12
			Fig. 1.15	13
			Fig. 1.16	14
			Fig. 1.17	15
			Fig. 1.18	16
			Fig. 1.19	17
			Fig. 1.20	18
		54 - An Introduction to Ecology and Biomes	Front Graphic	1133
			Fig. 54.1	1133
			Fig. 54.2	1134
			Fig. 54.3	1135
			Fig. 54.4	1137
			Fig. 54.5	1138
			Fig. 54.6	1138
			Fig. 54.7	1139
			Fig. 54.8	1140
			Fig. 54.9	1140
			Fig. 54.10	1140
			Fig. 54.11	1141
			Fig. 54.12	1142
			Fig. 54.13	1143
			Fig. 54.14	1144
			Fig. 54.15	1144
			Fig. 54.16	1145
			Fig. 54.17	1145

			Fig. 54.18	1146
			Fig. 54.19	1147
			Fig. 54.20	1147
			Fig. 54.21	1148
			Fig. 54.22	1149
			Fig. 54.23	1149
			Fig. 54.24	1150
			Fig. 54.25	1150
Campbell Biology: Concepts & Connections, 7th ed.	Jane Reece, Martha Taylor, Eric Simon, Jean Dickey, Richard Liebaert	1 - Biology: Exploring Life	Front Graphic	1
			Fig. 1.1	2
			Fig. 1.2	3
			Fig. 1.3	4
			Fig. 1.4	5
			Fig. 1.5	6
			Fig. 1.6	7
			Fig. 1.7A	8
			Fig. 1.7B	8
			Fig. 1.7C	8
			Fig. 1.7D	9
			Fig. 1.8	9
			Fig. 1.9A	10
			Fig. 1.9B	11
			Fig. 1.9C	11
			Fig. 1.9D	11
			Fig. 1.9E	11
			Fig. 1.10	12
		37 - Communities and Ecosystems	Front Graphic	739
			Fig. 37.3A	741
			Fig. 37.3B	741
			Fig. 37.4	741
			Fig. 37.5A	742
			Fig. 37.5B	742
			Fig. 37.6	743
			Fig. 37.7	743
			Fig. 37.8	744
			Fig. 37.9	745
			Fig. 37.10A	746
			Fig. 37.10B	746
			Fig. 37.11A	747
			Fig. 37.11B	747
			Fig. 37.11C	747
			Fig. 37.11D	747
			Fig. 37.12A	748

			Fig. 37.12B	748
			Fig. 37.13A	749
			Fig. 37.13B	749
			Fig. 37.13C	749
			Fig. 37.14	750
			Fig. 37.15	751
			Fig. 37.16A	751
			Fig. 37.16B	751
			Fig. 37.17	752
			Fig. 37.18	753
			Fig. 37.19	753
			Fig. 37.20	754
			Fig. 37.21	755
			Fig. 37.22A	756
			Fig. 37.22B	756
			Fig. 37.23A	757
			Fig. 37.23B	757
Biology, 9th ed.	Peter Raven, George Johnson, Kenneth Mason, Jonathan Losos, Susan Singer	1 - The Science of Biology	Front Graphic	1
			Fig. 1.1	2-3
			Fig. 1.2	5
			Fig. 1.3	5
			Fig. 1.4	6
			Fig. 1.5	8
			Fig. 1.6	9
			Fig. 1.7	9
			Fig. 1.8	10
			Fig. 1.9	11
			Fig. 1.10	11
			Fig. 1.11	12
			Fig. 1.12	13
			Fig. 1.13	14
		57 - Community Ecology	Front Graphic	1185
			Fig. 57.1	1186
			Fig. 57.2	1187
			Fig. 57.3	1187
			Fig. 57.4	1188
			Fig. 57.5	1189
			Fig. 57.6	1190
			Fig. 57.7	1191
			Fig. 57.8	1191
			Fig. 57.9	1192
			Fig. 57.10	1193
			Fig. 57.11	1194

			Fig. 57.12	1194
			Fig. 57.13	1195
			Fig. 57.14	1195
			Fig. 57.15	1196
			Fig. 57.16	1197
			Fig. 57.17	1197
			Fig. 57.18	1198
			Fig. 57.19	1199
			Fig. 57.20	1199
			Fig. 57.21	1200
			Fig. 57.22	1201
			Fig. 57.23	1201
			Fig. 57.24	1202
			Fig. 57.25	1203
			Fig. 57.26	1204
Biology: Life on Earth with Physiology, 9th ed.	Gerald Audesirk, Teresa Audesirk, Bruce Byers	1 - An Introduction to Life on Earth	Front graphic	1
			Fig. 1-1	3
			Fig. 1-2	4
			Fig. 1-3	5
			Fig. 1-4	5
			Fig. E1-1	6
			Fig. E1-2	7
			Fig. 1-5	8
			Fig. 1-6	10
			Fig. 1-7	11
			Fig. 1-8	11
			Fig. E1-3	12
			Fig. 1-9	13
			Fig. 1-10	14
			Fig. 1-11	15
			Fig. E1-4	16
			Fig. 1-12	17
		27 - Community Interactions	Front Graphic	511
			Fig. 27-1	513
			Fig. 27-2	514
			Fig. 27-3	515
			Fig. 27-4	516
			Fig. 27-5	516
			Fig. 27-6	517
			Fig. 27-7	517
			Fig. 27-8	518
			Fig. 27-9	518
			Fig. 27-10	519

			Fig. 27-11	519
			Fig. E27-1	520
			Fig. 27-12	521
			Fig. E27-2	522
			Fig. 27-13	523
			Fig. 27-14	524
			Fig. 27-15	525
			Fig. 27-16	526
			Fig. 27-17	527
			Fig. 27-18	528
			Fig. 27-19	529
Biology	Jay Phelan	1 - Scientific Thinking	Front Graphic	1
			No Fig. Num.	2
			Fig. 1-1	3
			Fig. 1-2	4
			Fig. 1-3	5
			Fig. 1-4	6
			No Fig. Num.	8
			Fig. 1-5	8
			No Fig. Num.	9
			Fig. 1-6	9
			Fig. 1-7	10
			Fig. 1-8	11
			Fig. 1-9	12
			Fig. 1-10	13
			Fig. 1-11	14
			Fig 1-12	15
			No Fig. Num.	17
			Fig. 1-13	18
			Fig. 1-14	19
			Fig. 1-15	21
			Fig. 1-16	22
			No Fig. Num.	23
			Fig. 1-17	24
			Fig. 1-18	25
			Fig. 1-19	26
			Fig. 1-20	27
			No Fig. Num.	28

			No Fig. Num.	29
		15 - Ecosystems and Communities	Front Graphic	549
			No Fig. Num.	550
			Fig. 15-1	550
			Fig. 15-2	551
			Fig. 15-3	552
			Fig. 15-4	553
			No Fig. Num.	554
			Fig. 15-5	554
			Fig. 15-6	555
			Fig. 15-7	556
			No Fig. Num.	556
			Fig. 15-8	557
			Fig. 15-9	558
			Fig. 15-10	559
			Fig. 15-11	560
			No Fig. Num.	561
			Fig. 15-12	562
			Fig. 15-13	562
			Fig. 15-14	564
			Fig. 15-15	564
			Fig. 15-16	565
			Fig. 15-17	566
			Fig. 15-18	567
			Fig. 15-19	568
			No Fig. Num.	568
			No Fig. Num.	568
			Fig. 15-20	569
			Fig. 15-21	570
			Fig. 15-22	571
			Fig. 15-23	572
			Fig. 15-24	574
			Fig. 15-25	575
			Fig. 15-26	575
			Fig. 15-27	576
			Fig. 15-28	577
			Fig. 15-29	578

			No Fig. Num.	579
			Fig. 15-30	580
			Fig. 15-31	581

Appendix B

Systems Rubric (SR) for evaluating biology textbook graphics for biological systems-based thinking

Textbook Title and Author:				
Chapter Title:				
Page and Figure Number:				
Primary Principles of Systems Biology	**Exemplary 3**	**Average 2**	**Weak 1**	**Points**
Networks	Uses multiple organisms showing the same phenomenon, not just an anthropocentric perspective Shows linkages to real life	Uses a single organism showing the same phenomenon, not just an anthropocentric perspective Shows linkages to real life	Only shows an anthropocentric perspective Does not show linkages to real life	
Nested Systems	Incorporates multiple perspective views	Shows only two levels or perspectives	Only shows one level or perspective	
Cycles	Use of before, during, and after images	Uses either before and during or during and after images	Uses only during images	
Flows	Shows positive and negative effects of a phenomenon	Shows only positive or negative effects of a phenomenon	Does not show any possible positive or negative effects of a phenomenon	
Development	Shows varying time stages and correct chronology	Shows varying time stages but inaccurate chronology	Only shows one time stage and no chronology	
Dynamic Balance	Demonstrates feedback loops and how these can affect normal functioning	Demonstrates feedback loops but does not show connections to normal functioning in organisms	Does not demonstrate any feedback loops	
Total Points/ Average Points				

Appendix C

Tuftian Rubric C for evaluating biology textbook graphics for Tuftian principles

Textbook Title and Author:			
Chapter Title:			
Page and Figure Number:			
Display Principles of Tuftian Graphics	**Meets Tuftian Principles 2**	**Lacks Tuftian Based Principles 1**	**Points**
Show the data	Clearly shows the data	Representation of data lacks focus or is unclear	
Avoid distortion	Clearly and accurately displays data, avoids misrepresentation	Cherry-picks a few key features while ignoring the rest or lacks proper scale	
Maximize data ink and avoid chart junk	Uses the least amount of data ink to display data	Uses fancy pictures or elaborate drawings that are unnecessary to demonstrate the concept	
Avoid chart junk	Does not use any unnecessary drawings or images	Uses unnecessary drawings or images	
Have a clear purpose	Purpose of the graphic or data is obvious to the reader	Purpose of the graphic is unclear or difficult to gather	
Clarify large data sets	Large sets of data are made more manageable	Large data sets appear unwieldy and confusing	
Use multi-variate displays of data to organize large data sets	Uses multivariate data for large data sets	Does not use multivariate data for large data sets	
Use data along with written descriptions	Numeric data is presented along with written descriptions	Numeric data is presented alone without any written descriptions	
Reveal the data in layers and create depth	Presents data in stages revealing findings in layers	Presents data all at once without creating depth	
Total Points/ Average Points			

Appendix D

Ethnographic Systems Rubric (ESR) for Ecologically-Based Graphic Classification

Textbook Title and Author:				
Chapter Title:				
Page and Figure No.:				
Foundations of Ecological Literacy	**Directly Systems-Based**	**Indirectly Systems-Based**	**Indirectly Reductionistic**	**Directly Reductionistic**
Empathy	Shows empathy for all life forms, shifting from a mindset of humans being separate and above to being fully integrated with other life forms.	Suggests empathy for other life forms and shows integration of humans with other life forms.	Lacks empathy for other life forms but does show some integration of humans with other life forms.	Shows no empathy and fully maintains humans as separate and above other life forms.
Visibility	Makes invisible practices visible, shows how actions affect other people, other life forms and the planet.	Suggests some invisible practices and shows how some actions may affect other people or other life forms.	Does not show any invisible practices but may suggest that some human processes might affect other life forms.	Does not show or suggest any invisible processes or practices that might affect other life forms or the planet.
Consequences	Predicts and shows what will happen from human action before that action is taken.	Suggests possible consequences of human action without directly showing them.	Suggests linkages but without consequences of human action, may emphasize consequences from other living things or systems.	Shows no linkages between human or non-human actions and effects on living systems.
Processes	Shows an understanding of the earth's processes and the earth's living and non-living cycles.	Suggests only parts of a cycle without completely explaining it.	Shows the Earth as independent parts instead of a collection of complex integrated cycles.	Does not show any aspects of systems or cycles only shows independent parts and the earth as primarily separate from humans.
Sustainability	Shows the quality to the web of complex relationships within any living community that required special attention and understanding by people. Develops cooperative thinking with people and other living things, implies human reasonability.	Suggests that the quality of the web of relationships can be changed and affected by people without clearly showing people integrated with the biosphere.	Shows some relationships but emphasizes people as independent from other living things.	Shows independent thinking of people without linkages to other groups of people or other living things.
Total				

Appendix E

Letter of permission of use from Dr. Gus Speth

From: On Behalf Of Gus Speth
Sent: Tuesday, August 28, 2012 6:48 AM
To: Brooks, Katherine

no problem. it is in the public domain and you are free to cite it. glad you found it useful. gus

On Fri, Aug 24, 2012 at 12:43 PM, Brooks, Katherine wrote:

Hello Dr. Speth,

I am currently completing my dissertation involving environmental literacy in post-secondary education at Louisiana State University. I came across a transcript of a lecture you gave in 2010 at the John H. Cafee memorial Lecture on Science and the Environment. I found it to be an eye-opening and inspiring lecture and was hoping that I might have your permission to use parts of that lecture in my dissertation and cite them appropriately. These are the sections I was most interested in quoting:

"Here at home, despite four decades of environmental effort, we are losing 6,000 acres of open space every day and 100,000 acres of wetlands every year. Since 1982 we have paved or otherwise developed an area the size of New York State. Forty percent of U.S. fish species are threatened with extinction, a third of amphibians, 20 percent of birds and mammals. Since the first Earth Day in 1970 we have increased the miles of paved roads by 50 percent and tripled the total miles driven. Solid waste generated per person is up 33 percent since 1970. Manicured mountains of trash are proliferating around our cities. Half our lakes and a third of our rivers still fail to meet the fishable and swimmable standard that the Clean Water Act said should be met by 1983. EPA reports that a third of our estuaries are in poor condition, and beach closings have reached a two-decade high. A third of Americans live in counties that fail to meet EPA air quality standards, which themselves are too weak."

"Half the world's tropical and temperate forests are now gone. The rate of deforestation in the tropics continues at about an acre a second, and has been for decades. Half the planet's wetlands are gone. An estimated 90 percent of the large predator fish are gone, and 75 percent of marine fisheries are now overfished or fished to capacity. Almost half of the world's corals are either lost or severely threatened. Species are disappearing at rates about 1,000 times faster than normal. The planet has not seen such a spasm of extinction in 65 million years, since the dinosaurs disappeared...

...Despite stern warnings now thirty years old, we have neglected to act to halt the buildup of greenhouse gases in the atmosphere and are now well beyond safe concentrations. Industrial processes are fixing nitrogen, making it biologically inactive, at a rate equal to natures's; one result is the development of hundreds of documented dead zones in the oceans due to overfertilization. Human actions already consume or destroy each year about 40 percent of nature's photosynthetic output, leaving too little for other species. Freshwater withdrawals are now over half of accessible runoff, and soon to be 70 percent. Water shortages are increasing in the United States and abroad. Aquatic habitats are being devastated. The following rivers no longer reach the oceans in the dry season: the Colorado, Yellow, Ganges, and the Nile, among others. We have treaties on most of these issues, yes but they are in the main toothless treaties."

Thank you so much for your time and I look forward to hearing from you.

Katherine E. Brooks

Appendix F

Letter of permission of use from Dr. Will Steffen

From: Will Steffen
Sent: Friday, August 24, 2012 7:57 PM
To: Brooks, Katherine
Subject: Re: Permission to use graphics

Dear Katherine,

Many thanks for the message. I am happy to give permission for use of the Figures you cited in your message in your dissertation.

With best wishes,

Will Steffen

On 25/08/12 2:17 AM, Brooks, Katherine wrote:

Hello Dr. Steffen,

I am currently completing my dissertation involving environmental literacy in post-secondary education at Louisiana State University. I came across your article "Observed Trends in Earth System Behavior" and found some of the graphs you used really fascinating. I was hoping that I might have your permission to use those graphs in my dissertation and cite them appropriately. I was most interested in a flow chart you used showing the interaction of human alteration with the biosphere and also some of the graphs that you compiled showing changes in human activity in the last 50 years and changes to the earth system in the last 50 years. Thank you so much for your time and I look forward to hearing from you.

Katherine E. Brooks

Appendix G

Letter of permission of use from Dr. Richard Duschl

Katherine,

Thanks - I pleased that the message of the image has come through to you. You have permission to use it in your dissertation. I have since expanded that image to contain more details. I will forward it to you in a separate email.

RA Duschl

On Fri, Aug 24, 2012 12:33 PM, "Brooks, Katherine" wrote:

Hello Dr. Duschl,

I am currently completing my dissertation involving environmental literacy in post-secondary education at Louisiana State University. I have read your book " Restructuring Science Education" and found the graphic that you use on the cover of your book to be helpful in describing the process of scientific understanding. I was hoping that I might have your permission to use that graphic in my dissertation and to cite it appropriately. Thank you so much for your time and I look forward to hearing from you.

Katherine E. Brooks

Vita

Katherine Ellen Brooks, a native of New Orleans, Louisiana, received her bachelor's degree at Texas A & M University in 1996 with a major in psychology and a strong emphasis on coursework in biology, wildlife and fisheries, and animal science. She then continued her education at the University of Nebraska - Lincoln, graduating with her Masters degree in biological- psychology. Her Master's thesis research focused on animal behavior, specifically sexual selection through auditory communication in Northern Cardinals. Since earning her Master's degree she has worked at the University of New Orleans as a teaching and research assistant in the departments of psychology and biology. She then began work as an instructor and later as an assistant professor at Our Lady of Holy Cross College in the Department of Natural Sciences. She anticipates graduating with her doctorate in December 2013 from Louisiana State University and plans to continue working as an educator in the biological sciences after graduation.